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**International Defense Acquisition Management and the Fifth-  
Generation Fighter Quandary**

**17 December 2012**

**by**

**BGen (Ret.) Raymond E. Franck, Senior Lecturer,  
Dr. Ira Lewis, Associate Professor  
Cadet First Class Holden Simmonds, and  
Dr. Bernard Udis, Visiting Research Professor  
Graduate School of Business & Public Policy**

**Naval Postgraduate School**

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# Abstract

This report continues a multi-year project intended to provide better understanding of global defense industries – integrating perspectives based on economic theory, politics (both domestic and international), and military affairs.

While the topics are disparate, the central focus of this report is the F-35. The NATO C-17 program is an inquiry into a model of international defense cooperation with different results from the negative experiences of the F-35 international partnership.

The T-X trainer is viewed not just as a replacement for the T-38, but also as a fifth-generation lead-in aircraft – with attendant complications and expense. We also focus on the F-35 program as an exercise in Graham Allison's model of governmental politics, and find this perspective to be useful in explaining the events and issues in that program.

Finally, we essay interpretation of F-35 difficulties and issues. All things considered, we believe the F-35 program raises considerable doubts about the sustainability of US weapon system acquisition practices (especially cutting-edge technology modernization of tactical fighters). Our report investigates the reasons for those doubts, and addresses aspects of a possibly-emerging new order in weapon system requirements and design practices.

**Keywords:** Global defense industries, F-35, NATO C-17 program, T-X trainer, weapon system acquisition



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# I. Introduction and Overview

This report represents the latest stage of a multi-year, multifaceted inquiry with the aim of better understanding the current, and emerging, international defense marketplace. Our intent in this stage of the project remains threefold: first, to better understand current defense industrial developments; second, to place those developments in context – particularly with respect to current military affairs, to include especially the ongoing Revolutions in Military Affairs (RMAs), and finally, to assess explanatory models of those developments.

Our first report, *Echoes Across the Pond ...* (Franck, Lewis, & Udis, 2008a), considered transatlantic defense-industrial issues focusing on the F-35 Joint Strike Fighter (JSF), the UK Defence Industrial Strategy of 2005, and the European Aeronautic Defence and Space Company's (EADS) KC-45 aerial tanker proposal.<sup>1</sup> We analyzed these “cases” with three well-known explanatory perspectives: offsets in international defense trade, transaction cost economics (TCE) and corporate strategy models. We assessed offsets as best for understanding the JSF, TCE for the UK's Defense Industrial Strategy, and corporate strategy models as best for the EADS-Northrop Grumman KC-45 proposal.

Our second report, *New Patterns of Collaboration and Rivalry ...* (Franck Lewis & Udis, 2008b) emphasized defense industrial firms – with consideration of Boeing's development of its 787 model; the KC-X competition (through the Summer of 2008), and European defense firms' (BAE Systems, EADS, Finmeccanica) strategies for entering the North American defense market. Two major findings were (1) the increasing technical and managerial complexities of modern aerospace systems, and (2) the increasing power of relatively agile defense suppliers relative to their increasingly bureaucratic customers.

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<sup>1</sup> The proposed aircraft was based on the A330, manufactured by Airbus (a division of EADS). This began as the “KC-30,” and was designated the KC-45 by the US Air Force in 2008. For further details, see Franck, Lewis & Udis, (2008a).



Third in the series was *Global Cooperation and Competition ...* (Franck, Lewis & Udis, 2010), which continued inquiries along the same general lines as above. We continued our efforts to better “map the terrain” of the global defense marketplace, discover useful explanatory paradigms, and to assess their relative explanatory powers. We considered the remarkable travails of the A-400M transport development project – which came in very late and much over budget. The A-400M (military) case turned out to be a useful companion to our previous Boeing 787 (commercial) case. Both illustrated the increasingly complexity of international development projects – and the problems that emerge.

The possibly emerging Nordic defense bloc is a potential source of significant change in the global defense marketplace. However, we found a rather complex situation – with significant attractions to other Nordic states, but also close and highly useful ties with partners outside the Nordic region (especially the United States).

Finally, our KC-X competition inquiry (third iteration) considered the explanatory power of two views of the US defense establishment (broadly defined) in the defense marketplace: the traditional model of sovereign monopsonist versus the governmental politics (Model III) originating with Graham Allison (Allison & Zelikow, 1999).

Our fourth effort, *Emerging Patterns in the Global Defense Industry* (Franck, Lewis, Matthews & Udis, 2011) continued the themes of the first three report: the still-ongoing KC-X competition, the C-27 transport, and unmanned aerial vehicles (UAVs). The remarkably prolonged nature of the KC-X selection process was clearly not due to technical immaturity. Both the Boeing and Airbus proposals featured mature designs – with variations already in service with other air forces. The KC-X continued to illustrate the bureaucratic, legal and political obstacles to acquisition in the United States – and their potential to sidetrack source selection processes.

The C-27 is a small air transport of Italian design, and serves (even with a truncated US program) the increasingly international nature of aerospace projects and sometimes complicated relationships between (and among) defense enterprises and



their defense customers. UAVs involve a range of designs, with a wide range of missions that include surveillance and strike. We essayed a discussion of UAVs in context as a major development in both contemporary military affairs and in the defense industrial base. UAVs are an important part of two ongoing RMAs. They are an important continuation of the Reconnaissance-Strike Complex embodiment of the RMA first demonstrated in the Gulf War of 1991. They are also useful countermeasures against the RMA originating with Al-Qaeda, the Taliban, and other terrorist and insurgent groups. (Both RMAs rely on new developments in Information Technology as basic enablers.)

The effect of UAVs on the defense market will possibly prove even more profound. The relative simplicity and cheapness of UAVs means that these systems can be developed with company resources outside the normal defense acquisition system—bypassing its complex and lengthy processes. Simplicity and cheapness also mean that a significant part of the defense aerospace market is now open to smaller companies. Thus, small countries possessing high technology can compete effectively in the UAV market; Israel, for example, has done just that.

Our latest published report (prior to this one), *Global Aerospace Industries: Rapid Changes Ahead?* (Franck, Lewis, & Udis, 2012), pursued the same research objectives already discussed, but was more focused in that it dealt with aspects of the heated rivalry between EADS and Boeing (two giant aerospace firms). The Boeing-EADS rivalry has been a major constellation in the firmament of the global defense marketplace. Two venues for that rivalry have been narrow-body airliners (Boeing 737 [B737] versus Airbus 320 [A320]), and the lengthy KC-X competition. These were the main topics of that research.

We discussed the final chapter (hopefully) in the saga of KC-X competitions. It appears the end came with a whimper rather than a bang – with all major players (including Boeing and EADS) weary of the affair. We also considered the effects of the overall experience on USAF acquisition processes and related capabilities. A mixed view emerged.





The B737-A320 rivalry has likewise been vigorously pursued by both parties, but the international market has offered ample opportunities for profit to both. The narrow-body airliners have, in a very real sense, provided the resources for both firms to pursue wide-body airliners (e.g., B787, A380), military transports (e.g., A-400M), and aerial tankers. However, that market is becoming more contestable (as defined in Baumol, et al., 1982). A number of potential challengers have emerged. These include regional jet manufacturers in Brazil and Canada, and also firms in China and Russia. If the market changes from duopoly (two main suppliers) to a more competitive structure, then significant changes could occur fairly rapidly. Among other things, Boeing and Airbus profits from narrow-body airliners could decrease significantly – with repercussions for both commercial and defense aerospace markets.

Our current effort deals with a number of issues related to aerospace projects in a global market, with Fifth-Generation Fighters, and related difficulties, being the unifying theme. Chapter II discusses international aspects of the US-led C-17 program, focusing on NATO participation. In a very real sense, this is a continuation of our previous work on the F/A-18 partnership in the context of foreign military sales and export controls (Franck, Lewis, Udis, 2011a). This inquiry includes interviews with anonymous NATO subject matter experts on a number of aspects of the C-17 in NATO air forces. A number of interesting findings emerge – including the advantages to working with a mature system with a lead nation, and the relative ease of international partnerships involving transport aircraft (e.g., C-17) compared to fighters (such as F-16 and F-35). This contrasts with the structure of the F-35 partnership, which involves a front-line fighter aircraft plus shared responsibility for design and development.

Chapter III reports on developments of the US Air Force new flight trainer (T-X) program. The T-X is intended to replace the T-38. However, it has a number of complications. Chief among these are (a) its ties to the new fifth generation of tactical fighters – which are computer-intensive (as well as stealthy) designs, and (b) the various international partnerships (formed and potential) that will shape the source selection for this aircraft.



Chapter IV considers the Joint Strike Fighter within the context of Allison's Model III (Governmental Politics, Allison & Zelikow, 1999). This is another look at the "quarrelsome committee" hypothesis which emerged from consideration of the KC-X selection process (Franck, Lewis, Udis, 2009). In a later report (2010), we found that Allison's Model III was a useful explanatory paradigm for the many chapters in the KC-X story. In this case, Model III also works reasonably well for F-35 Joint Strike Fighter development, although the committee does not appear nearly as quarrelsome as was the case for the KC-X. That situation might be changing, however. LtGen Bogdan, the incoming F-35 Program Executive, recently described DoD relations with Lockheed Martin as worst seen in some time (Bogdan, 2012).

Chapter V is intended to raise some questions about the continued viability, and advisability, of current defense acquisition practices – with focus on tactical fighters (especially the F-35). The F-35 has immense potential, but it's not clear that it will develop that potential in a timely manner, or at a cost that is fiscally consistent with timely fielding. It's also not clear at this time whether there will be large numbers of fully-operational Joint Strike Fighters (JSF, F-35) ahead of effective countermeasures to fifth-generation fighters.

All things considered, there is reason to believe a new era of (a) "good & cheap enough" and (b) living with "legacy" systems may well replace the current policy of best-available technology. Chapter V discusses extant elements of that possibly emerging new era.



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## II. C-17 Globemaster III and NATO

This chapter is divided into three sections. The first presents history and operations of the C-17 aircraft at large. The second, which focuses on the NATO experience with the aircraft. Although the number of planes involved in the latter phase is small (three to date), the structure and operations of the NATO strategic airlifter program are unique and of interest to some observers as a possible model for other multinational acquisition and operation of expensive military equipment. That leads to the third part: is C-17-in-NATO program a useful model for future international cooperation? We addressed that question through interviews with subject matter experts,<sup>2</sup> and report those results in the third section of this chapter. We take the bottom line answer to our main question (useful model) to be “yes, if done carefully.”

### A. C-17 History and Operations<sup>3</sup>

The Boeing C-17 Globemaster III is a four-engine, long-range military transport aircraft developed originally in the 1980s and early 1990s by McDonnell Douglas Aircraft Company (later absorbed by Boeing). It is a strategic airlifter used to move cargo, weapons, and troops over long distances and, yet, has been designed also to operate from relatively short and unimproved landing strips. This factor gives it the ability to be used as a tactical carrier for relatively short distances when necessary.

The C-17 has a maximum payload of 170,900 pounds and a range of 2800 nautical miles with a cruising speed of Mach 0.77 and a ceiling of 45,000 feet. It is powered by four reversible Pratt and Whitney F117-PW-100 turbofan engines, each rated at 40,400 pounds. The aircraft operates with a three person crew (pilot, copilot, and loadmaster), and is capable of midair refueling.

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<sup>2</sup> Our interview respondents agreed to participate with a condition of anonymity.

<sup>3</sup> Our material in this discussion is drawn from Boeing C-17 Globemaster III (2012); Airlift (2012), Aboulafia (2011).



The C-17 is currently operated by the air forces of the United States, the UK, Australia, Canada, NATO Strategic Airlift Capability Program, Qatar, and the United Arab Emirates. In addition, South Korea has allocated funds for several C-17s and Kuwait has indicated an interest in acquiring the aircraft. It should be noted that through the NATO program, a number of additional countries are participating in C-17 operations (Bulgaria, Estonia, Hungary, Lithuania, the Netherlands, Norway, Poland, Romania, Slovenia, and two Partnership for Peace countries – Sweden and Finland). Another important development was the selection by the Indian Air Force of the C-17 to fulfill its requirement for a Very Heavy Lift Transport Aircraft. In February 2011 India and Boeing announced the order for ten C-17s with an option to buy six additional aircraft.

By April 2011, 239 production C-17s had been delivered with the USAF accounting for 210. The production history of the C-17 includes several planned closings of its production line with subsequent extensions as new orders arrived. Looking ahead, Richard Aboulafia (2010) of the Teal Group has identified additional likely orders which could bring total C-17 output to 290 aircraft, not counting one early prototype.

## **1. Development History**

In search of a successor to the C-130 Hercules tactical cargo aircraft in the 1970s, the USAF instituted a competition for an Advanced Medium Short TakeOff and Landing (AMST) aircraft. Boeing's entry was designated YC-14 while McDonnell Douglas countered with its YC-15. Although both candidates met the formal requirements, the USAF cancelled the AMST competition without a selection being made. In November 1979 the USAF introduced a C-X program for the development of a larger version of the AMST with a longer range. In part this reflected the ravages of the age and operating tempo on its sizeable fleet of Lockheed-141 Starlifter cargo transports coupled with a growing need for increased strategic airlift capabilities.



This was followed in 1980 by a USAF solicitation to industry for the design and development of a new strategic airlifter. Shortly thereafter the Air Force issued a Draft Request for Proposals (RfPs) which included responses to several mission scenarios and more general requirements which suggested an aircraft about one half the size of a C-5A.

Responses to the RfP for the C-X were in USAF hands by January 1981, and in late August of that year the McDonnell Douglas proposal was announced as the winner of the competition. However, the USAF issued a *caveat* that victory of the McDonnell plane in the design competition was not equivalent to a commitment to undertake development of the aircraft. A number of factors contributed to the delay, several of which were exogenous to the C-17 proposal itself, such as the pursuit of other aircraft needs such as lengthening the C-141As, ordering additional C-5s, purchasing additional KC-10s and expansion of the Civil Reserve Air Fleet. The impact of such decisions on the budget resulted in a four year delay although small amounts were added to the budgets of FY1983 and FY1984 which allowed preliminary design work on the C-17 to continue as well as engine certification. In December of 1985 a full scale development contract was finally awarded which envisioned a first flight in 1990 and a requirement for 210 C-17 aircraft.

Any expectation that the development process would enjoy smooth sailing after these early problems was not to be realized. The late 1980s continued to be marked with further development problems and very modest funding. In particular, delays in the development of such essential elements as the electronic flight control system led to Honeywell being replaced by GE Aerospace and forced the C-17's first flight to be delayed to December 1990 which, in turn, threatened the meeting of other important milestone dates. Frustrated by such problems and subsequent delays in the flight test program and initial production deliveries, the Congressional Appropriations Conference reduced C-17 procurement funding for FY1990 by \$414 million to \$1,110 million. Further, in April 1990, then Secretary of Defense Richard Cheney announced a reduction in the total planned procurement of C-17s from 210 to 120.



Additional technical and financial problems were encountered during 1990 and 1991. Most of these were related to excessive aircraft weight and avionics integration. The year 1992 saw a continuation of difficulties for the C-17 ranging from further delays to an embarrassing episode dealing with possible illegal payments by the Air Force to McDonnell Douglas outside standard operating procedures. The Air Force held back \$100 million of progress payments in October 1992 following a failure of the aircraft to pass a stress test of the wings.

Problems continued during early 1993 including a stubborn continuation of weight gains and a crack in a main landing gear part during a heavy load test on the first C-17 production model. Pressed for results, the Air Force provided \$62.8 million to McDonnell Douglas in early February for long lead time parts funding for eight C-17s.

At that time the C-17 was clearly viewed as a troubled program and in mid-December of 1993, the Defense Department presented a new plan designed to resolve the dilemma. McDonnell Douglas was given two years to deal successfully with the production and cost overrun troubles or accept the program's termination with the delivery of the 40<sup>th</sup> aircraft. McDonnell Douglas was to drop \$1.2 billion in claims against the government and commit \$454 million for flight testing and management improvements. As *quid pro quo*, DoD would settle \$237 million in claims against the company and devote \$111 million to the flight test program and other miscellaneous changes. Also important was the relaxation of several performance specifications. Improvements were slow to develop and in April 1994 the program was still over budget while weight, fuel burn, payload, and range specifications were unmet. Several tests to determine the aircraft's airworthiness were failed and technical problems with mission software and landing gear remained unsolved.

A combination of requirements revisions and technical progress served to deliver significant improvements finally, and by the mid-1990s many of the remaining problems had been corrected. In November 1995, Deputy Defense Secretary John White declared that the C-17 would continue to be considered the core airlifter of the USAF with a fleet of 120 aircraft. This decision ended the two year probationary period for the



McDonnell Douglas C-17. In January 1995 the first C-17 squadron had been declared operational and the following year the Air Force ordered an additional 80 aircraft bringing the total to 120.

In 1995 the C-17 team was awarded the National Aeronautic Association's Collier Trophy for outstanding achievement in aeronautics and astronautics for the year 1994. The citation read as follows: "The 1994 Collier Trophy was awarded to the United States Air Force, the McDonnell Douglas Corporation, the United States Army, and the C-17 Industrial Team of subcontractors and suppliers for designing, developing, producing and placing into service the C-17 Globemaster III, whose performance and efficiency make it the most versatile airlift aircraft in aviation history" (Slack, 15 September 2012).<sup>4</sup>

After the 1997 McDonnell Douglas-Boeing merger, the Boeing Company offered a significant price reduction in 1999, contingent upon the Air Force acquiring 60 additional C-17 aircraft. The offer was accepted and in August 2002 the total C-17 order was increased to 180. By 2007 the number of C-17s on order for the USAF had reached 190 and the number continued to grow. As noted above, by April 2011, 230 production C-17s had been delivered with 210 to the USAF. When contracted aircraft become available, the USAF inventory could reach 223 with a consequent lengthening of the production run.

Part of this rapid growth reflects the familiar conflict between the Air Force's estimate of its needs and Congressional efforts to protect jobs in vulnerable districts and states. The production history of the C-17 has been marked by several planned closings of its production line followed by subsequent extensions to meet the needs of additional domestic and export orders. It is interesting to note that prior to his retirement from office, Defense Secretary Robert Gates listed ending the C-17 production line as one of his four most important goals for FY2010-FY2011. That intention has not yet

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<sup>4</sup> It should be noted that this award was due to the performance of the aircraft – not because of its development history.





been fulfilled as the impressive capabilities of this aircraft have become better known. Another consideration supporting a preservation of the C-17 assembly line is found in the heavy usage this aircraft has experienced in the Iraqi and Afghanistan conflicts and the consequently more rapid than expected aging of the earlier C-17 airframes.

## **2. Logistics and Maintenance**

The market for military aircraft is not characterized by a philosophy of "sell them and forget them." The prime producers have a continuing role in helping the service customer keep its aircraft ready and operating effectively. In multinational projects like the C-17, the customers are often widely dispersed geographically and display different levels of mechanical and engineering skills in domestic work forces. Wide variations in administrative and managerial experience are also encountered. Keeping prudent levels of spare parts and consumables in the plants of all users can often become highly expensive.

A firm's reputation is a valuable asset and an aircraft manufacturer in particular has a vested interest in building a public image of safety and effectiveness in its product. Thus, anything it can do to insure proper maintenance and high standards of operation would be advantageous. Factors such as these help explain the care with which major producers have developed systems to increase the likelihood that their products will be operated safely and effectively. When the USAF in the case of the C-17 (or the US Navy in the case of the F/A-18) is the major user of the system, it shares the principal contractor's interest in the safety and proper use of the product, As will be emphasized later in this report, close cooperation between the US military branch and the contractor will increase the probability of a successful system to manage maintenance and logistical issues for all users.

The logistics system developed for the C-17 is known as the Globemaster III Integrated Sustainment Program (GISP) and is based on the concept of a virtual fleet (VF) whose maintenance and logistical issues are addressed without distinctions based on details of purchase (foreign military sale or direct sale) or organizational attachment



(NATO or non-NATO). The goal is to treat all C-17 users as part of an all-inclusive user community whose members can depend on a world-wide, seamless system to meet their maintenance and/or logistical needs.

More details on the structure and operation of the virtual fleet follow. After identifying the large number of stakeholders in the C-17 program, an unpublished document (Bailey and Matlock, 2011) presents the roles of the participating groups in the virtual fleet – the participating nations, the USAF program office, and Boeing.<sup>5</sup>

Participating Nation – Committed to the vision, principles and responsibilities in the virtual fleet strategy; contributing resources consistent with membership in that fleet (spares, infrastructure, manpower and training); maintaining USAF equivalent certification; fully participating in sustainment contracts; sharing operational experience and best practices to improve the overall effectiveness and efficiency of the C-17 virtual fleet; and consulting with other partners regarding issues likely to impact the entire fleet.<sup>6</sup>

USAF Program Office – Acquisition agent for the partners (contract management, airworthiness, and management of government furnished equipment); research and development (engineering authority, test and evaluation, and configuration management); act as product support manager for sustainment (spares and support equipment; depot maintenance and modifications scheduling; and crisis management, root cause analysis, and corrective action).

Boeing – Supply chain manager for C-17 spares as stated in the relevant sustainment contract. Performs supply, maintenance, and mod services at main operating bases; provides engineering and airworthiness support at the factory in

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<sup>5</sup> Bailey and Matlock are, respectively, Air Force and Boeing employees. .

<sup>6</sup> This goal is facilitated by participating in annual conferences hosted by Boeing.



Long Beach and main operating bases; and provide recovery aircraft support services to any C-17 operator at any location.

Almost by definition, multinational acquisitions involve third party transfers of data and parts. In the case of the C-17, third party transfers of technical data were approved in April 2007 for Canada, Australia, the NATO Airlift Management Agency (NAMA), and the United Kingdom. Blanket third party transfers of spares were approved in April 2010 for Canada, Australia, NAMA, and the United Kingdom. Subsequently, Qatar and the United Arab Emirates (UAE) were added to the list while India's application is now under consideration.

Cost sharing in multinational projects is always a sensitive topic. The C-17 sustainment contract provides support services and material support for the entire virtual fleet with common costs shared on a prorated basis. Such costs are based on the primary inventory, number of flying hours, and engine cycles. Occasionally countries request unique features on their aircraft and in such cases, the associated costs are billed to the individual user. Such requests are discouraged since deviations from the basic design reduce the cost advantages of commonality.

Random inquiries among C-17 users yielded a high level of satisfaction in its operational qualities which would seem to be confirmed by its impressive export sales record. A report to a British Parliamentary Defence Committee on lessons learned from the A400M experience described the C-17 as "a widely admired aircraft" (Taylor, 2011, p. 7).

## B. The NATO C-17 Experience

Although the actual number of C-17s in this program is still small (only three flying), its apparent success as a structure for multinational procurement of expensive aircraft has been seen by some as a model worthy of future emulation. What follows is an examination of the NATO experience and some observations on its usefulness as such a model. The approach taken examines the issue of lessons learned and the process of transfer of such lessons between successive models.



## **1. SALIS: An Interim Step Toward the Strategic Airlift Capability**

As NATO's involvement in international problems outside of the territory of its members grew in the early 1990s its deficiency in its stock of strategic airlifters became a serious problem and led to what some would consider an unlikely decision – the leasing of very large Russian cargo aircraft (Strategic AirLift Interim Solution [SALIS], 2012).

At an annual spring meeting in Brussels in June 2003, NATO Defense Ministers signed letters of intent dealing with strategic air- and sealift. The letters on aircraft were signed by Canada, the Czech Republic, Denmark, France, Germany Hungary, Luxembourg, Norway, Poland, Portugal and Turkey. At a June 2004 Istanbul Summit, 15 Defense Ministers signed a Memorandum of Understanding calling for a operational airlift with very large cargo capability by 2005, using as many as six Antonov An-124 aircraft. The Defense Ministers of Bulgaria and Romania also joined the group by signing letters of intent. The consortium members entered into a contract in January 2006 with Ruslan SALIS GmbH, a subsidiary of the Russian firm Volga Dnepr based in Leipzig. The original Western signatories added Sweden to their number in a ceremony in Leipzig in March 2006 which celebrated the legal beginning of the multinational relationship. The original contract was written with a duration of three years but there have been several extensions negotiated which now run to the end of 2012. During the interim, Finland and Poland have also joined the group. The SALIS aircraft (AN-124-100s) have been contributed to the program by Russia's Volga-Dnepr and Ukraine's ADB. Sorties have been flown from Germany to Afghanistan, contracted for with the Allied Movement Coordination Centre at Supreme Headquarters Allied Powers Europe.

As the name SALIS (which stands for Strategic Airlift Interim Solution) indicates, this program was designed to handle a temporary need until more permanent arrangements could be established. During the research for this report serious doubts were expressed concerning the wisdom of these leases, given the ongoing geopolitical problems that remain between Russia and the US and related questions about the professionalism and competence of the Russian aircrews. Specific comments by one of



our (anonymous) respondents present a more precise complaint and indicate a connection between SALIS and the C-17 Globemaster III program:

"The SALIS nations who became (Strategic Airlift Capability) nations always complained to me about availability of aircraft when they were needed under SALIS, and they indicated a suspicion that availability was as much politically driven as having aircraft available to fly. This is the reason the 'ownership' model of (Strategic Airlift Capability) was appealing to the SALIS nations who signed up and paid for (membership)."

## **2. The NATO Strategic Airlift Capability<sup>7</sup>**

The Strategic Airlift Capability is a 12-country consortium designed to jointly own and operate three C-17 Globemaster III heavy airlifters to facilitate the transport of personnel and heavy equipment for military and/or humanitarian purposes anywhere around the globe. The membership consists of 10 NATO member countries (and 2 non-NATO countries associated with the Partnership for Peace (PfP). The NATO members are Bulgaria, Estonia, Hungary, Lithuania, the Netherlands, Norway, Poland, Romania, Slovenia, and the United States. The non-NATO countries are Sweden and Finland. Five other European nations that were initial participants withdrew either during negotiations (Denmark and Slovakia), after negotiations (Latvia), or during signature (the Czech Republic and Italy). Apparently, cost considerations and issues of legal responsibility were the principal obstacles to their joining. Missions have been flown for NATO, the European Union (EU), and the United Nations (UN). The consortium's aircraft are based at a former Warsaw Pact air base located in central Hungary and operate from that base at Pöpa. The operational organization is known as the Heavy Airlift Wing (HAW). The program operates under a steering committee chaired by a US Air Force General and the original commander of the HAW was a USAF Colonel, aided

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<sup>7</sup> Much of the factual material in this section draws upon NATO Strategic Airlift Capability, 2012 and Tirpak, 2011b. Additional material comes from confidential interviews with knowledgeable persons associated with the NATO C-17 program. Also of use was an unpublished, undated and anonymous document "Strategic Airlift Capability: Lessons Learned".



by a Vice Commander from the Swedish Air Force. The Steering Committee oversees the program to be sure the airlift capability is delivered the way the contributing nations intend. NATO and its operational commanders are "customers" for the capability but they do not exercise operational command and control over the capability.

The original annual flying hours of the NATO C-17 wing were set at 3500 and each partner selected an annual number of hours of that total for its own anticipated annual use. This share of annual usage was also applied to the annual cost of the wing to determine respective member financial contributions. The US requested 1000 hours and hence pays approximately one third of the costs. This is the largest share and probably explains the fact that the first two HAW commanders were American officers. The extended experience of the USAF in flying the C-17 also probably contributed to the initial Commanding Officers being from the US. Sweden at 550 hours ranks second among users which may explain why Swedish officers served as the first two vice commanders. Nothing in the charter allocates positions based on nationality and rotation is likely in the future. The Popa base operates with a personnel complement of approximately 140; in addition, 50 Boeing employees work at the base performing virtually all aircraft maintenance. Crew chiefs however, are drawn from military personnel assigned to the HAW.

### **3. History of the NATO Strategic Airlift Capability**

The concept of a Strategic Airlift Capability for which NATO would acquire C-17s had been discussed for several years but a real development of the will to do so was not reached on the part of NATO members for some time. During this period, the US assisted several NATO and allied nations (the UK, Canada, and Australia) to independently acquire C-17 aircraft in the interest of interoperability and the development of improved partner capacity. In addition, Sweden was seriously contemplating buying C-17 aircraft from Boeing to move troops and equipment in furtherance of its UN peacekeeping obligations, but was finding the associated costs troublesome. At about this time (mid-2006) the strategic airlift concept was gaining some support within NATO headquarters as a way to provide strategic airlift services at



a manageable cost via collaborative efforts. A leading role was played by the US Assistant Secretary General for Defence Investment, Marshall S. Billingslea. The acquisition and support of these C-17 aircraft would be carried out under the Foreign Military Sales (FMS) program of the USAF.

Reaching agreement on the details of this program was not easy. Originally, some saw the NATO E-3 program as a possible model for the Strategic Airlift Capability program but it became clear that such a program design would not work for the NATO C-17 venture. The fact that there were non-NATO nations in the program would be an obstacle to organizing it under NATO command and control authority. Indeed, ultimately the NATO designation was dropped from the program name. In addition, three NATO member states (France, Germany, and Spain) were partners in the development of the A-400M cargo aircraft and they feared that adoption of the C-17 as the strategic airlifter would be a possible obstacle to the selection of their aircraft (already quite delayed in development) for that role. Given the unanimity rule for NATO decisions, their objection to the C-17 could stifle its adoption for the Strategic Airlift Capability program. This problem could be finessed by organizing the program outside of the formal NATO structure where the unanimity rule would no longer apply.

Another issue was how the liability would be determination in the event of safety problems associated with multinational operating crews. According to a former USAF official, satisfactory progress at the working level soon encountered obstacles within the several DoD bureaucracies which took high level intervention to overcome. A number of non-trivial problems remained to be solved involving such issues as the final structure of the international group; how it would be financed and sustained; the operational chain of command including the tasking of aircraft and the assignment of multinational aircrews; and basing and flagging of the aircraft.

All manner of legal questions needed to be resolved. The uniqueness of the program made it difficult to look to other programs for guidance. Ultimately such questions were resolved, with a great deal of collaboration and in remarkably short order. The HAW went from concept to the start of base operation in two and a half





years with many missions to allied forces in Afghanistan among the early assignments as well as humanitarian flights to Haiti and Pakistan after natural disasters.

The US has played a major role in the early years of the organization having contributed one of the C-17 aircraft, a third of the personnel and of the cost. The consortium receives crew training at the Altus Air Force Base in Oklahoma. Consequently USAF regulations and procedures were adopted initially in the Heavy Wing at Popa and the overall program, but the US presence is expected to become less dominant with experience and the multinational organization developing its own identity. Presently the aircraft are marked with Hungarian identification and the letters "SAC."

#### **4. Problems of the Current Structure and Organization**

As might have been expected in a multinational operating air base, differences in language, culture and experience posed difficulties. Orders and other important documents have had to be translated into several languages. Differences in national personnel structures were sometimes a problem. For example, Norway's air force is staffed only with commissioned officers using no enlisted personnel. Pilot experiences have varied widely, and missions to combat zones like Afghanistan have raised difficulties requiring creative solutions. Occasionally some crew members cannot be ordered to particular missions since their nations maintain a list of forbidden destinations in furtherance of particular foreign policy considerations. In such circumstances, while no nation can veto a mission, they can order their nationals not to participate. Senior base officers can issue orders to personnel, but they cannot discipline a person not in their particular national service branch. Member states have concurred in a decision to allow the base commander authority to make the final decision in the event of an unresolved issue.

Other problems have grown out of the base's location at Popa and its range of equipment. Thus, the train freight ramp cannot be used to handle heavier items of cargo which limits the rail trans-shipment capacity. A major limitation of the base is the absence of a hanger large enough to accommodate a complete C-17 aircraft. This





makes aircraft maintenance in winter very difficult, and major work must be performed in Jackson, Mississippi. This is true also for flight simulators used to train flight crew members.

Another limitation is that imposed by the small size of the Strategic Airlift Capability fleet - three aircraft – which is inadequate to meet the current demand for the Wing's services. The membership size could possibly be expanded, especially if fleet size is enlarged, but the capabilities of potential new members would have to be considered carefully. Even now, not all current members are in a position to contribute flight personnel, and therefore some make contributions in kind -- providing security forces and other staff.

### C. A Model to Emulate?

An important goal of this study was to determine whether the Strategic Airlift Capability experience might provide a model to be used in structuring other multinational cooperative efforts to provide advanced military equipment at a lower cost than would be encountered in single nation efforts to acquire such equipment. This question has many facets, one of the most important of which deals with the nature of technology transfer – not just defined in a narrow dimension, but also involving the transfer of organizational and operational structures.

We were fortunate to identify a small number of persons who played an important role in the development of the Strategic Airlift Capability and who brought with them similar experience in other multinational efforts. They were generous with their time and cooperated by answering several questions which were put to them with a guarantee of confidentiality and no attribution. Their contributions have not been limited to the following responses and much of the foregoing material has benefitted from their experience and willingness to share their expertise.

1. Have you seen evidence of a possible transfer of lessons learned (things to avoid or possibly pursue) between successive NATO acquisitions in terms of organizational structure or operational procedures?



*Response I:* I have seen some evidence that lessons from one NATO major acquisition program have been taken into account when undertaking the next, but the benefits have been limited due to national economies, national self-interest with respect to technology transfer, and the demand for inefficient industrial participation agreements between the defense contractor and the contributing nations other than the USA. To further discourage progress in the short term, NATO has chosen the current widespread economic crisis as a catalyst to "reform NATO", expressly including its several specialized procurement and support agencies. This effort – intended to combine 14 specialized agencies into 3 broadly composed agencies (communications & information, procurement, and support) – has been a distraction to the existing agencies, a disincentive to creating new programs in the short term, and is being used by some NATO nations to fulfill (in my opinion) an agenda that is more supportive of EU institutions than it is for NATO. It will be interesting to see the results of Agency Reform from the vantage point of 5 years in the future.

*Response II:* One challenge that is being faced today by NATO AWACS and NATO AGS (Alliance Ground Surveillance Program) is to get all NATO nations to agree to pay for operations and support costs. On NATO AWACS, O&S costs (other than deployment) are paid for by the nations that bought the aircraft vice NATO as a whole. There are activities under way to try and change NATO AWACS to common O&S funding so that the sponsoring nations don't keep subsidizing the alliance on things like spares and depot maintenance.

This same argument is underway on NATO AGS where it has been "assumed" the O&S would be common funded but this has not been subscribed to by all nations including particularly France. In the media you can see indications that deals are being made with France to get their support. This was only indirectly faced on the C-17 Strategic Airlift Capability program because the aircraft is not operated within the NATO force structure like in the case of AWACS and hopefully in the future AGS. In the C-17 Strategic Airlift Capability program, the nations operate the aircraft through the multinational wing they have developed



and own (and pay for) a share of the annual flight hours which, if they desire, can be used to support their NATO commitments.

While it might make sense for a group of nations to fund the development and procurement of a NATO-owned asset as they can receive industrial participation benefits and technology transfer/maturation, the idea of these countries paying the complete sustainment bill is not resonating particularly with the US. This type of approach is needed to achieve the "smart defense" initiatives mentioned in the January 2012 Strategic Guidance for the DoD<sup>8</sup>.

As far as structuring a program acquisition and management strategy, it is my experience that all of the NATO "cooperative" programs have their own nuances which drive different approaches. I don't see a cookbook solution to structuring a program. What we did on the NATO C-17 was look at all of the other programs managed through a NATO Production and Logistics Organization (NPLO) and evaluate how they addressed certain aspects and then adopted what fit the SAC program".

2. Are there differences in the type of equipment procured (fighter versus cargo aircraft) which either encourage or inhibit transfer of experience between projects?

*Response 1:* Because I understand the context of your question, allow me to make some general observations before attempting to answer your specific question. NATO has not proven to be very good at projects that require high technology R&D. Although the US, Australia, Canada, UK and to a lesser extent other Western European nations share great mutual trust and respect for each other's cooperative R&D and co-production capabilities and have cooperatively achieved impressive results in developing, producing, and deploying defense capabilities; those successes have been country-specific rather than based on

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<sup>8</sup> We believe the actual source for "smart defense initiatives" is more a NATO declaration of May 2012, instead of the US Defense Strategic Planning Guidance (Maintaining US Leadership) of the same year. (That is, NATO Summit Declaration, 2012; vice The White House, 2012).



the type of equipment. Another aspect that is a success predictor is "what is hot today"; if it's hot, national self-interest equates to moving the project to the front of the queue, assigning the most capable agreement negotiators, assigning the most capable joint program office managers, and providing funding at a level that almost always assures success. Of course, despite high priorities and boat-loads of cash, programs can go south as JSF may do if we are not very careful from here forward. However, most hot programs among the nations cited above succeed because of priorities, trust, mutual respect, and willingness to give-and-take during the execution of major acquisition programs.

Focusing more on your specific question, the poster child NATO acquisition program has been the C-17 effort. It was quick, it was affordable, very visible, and has lived up to expectations. By comparison, the NATO Alliance Ground Surveillance (AGS) Program was (a) model for the Program with its Charter and MOU negotiations completed a few months before the start of (actual operations).<sup>9</sup> Yet AGS is still not on contract and has suffered from a slow but steady decline while the contract was under negotiation, national economies failed, and at least one wealthy nation became disillusioned by the bickering and their NATO agency's inability to get to contract. Both involved acquisition of new aircraft, yet one succeeded while the other has floundered – what was different? In my opinion SAC succeeded because:

- a) C-17 was a mature weapon system that was available off-the-shelf without necessary adaptations or distribution of inefficient participation in production
- b) The contributing nations had a national requirement to use the C-17 to meet their commitments to NATO, the UN, their forces, and to their citizens that might be isolated due to a national disaster (e.g., the great Tsunami) or political unrest (e.g., Lebanon or nations

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<sup>9</sup> Here a few words of the respondent have been altered while preserving his meaning in order to protect the anonymity of the contributor.



affected by the so-called Arab Spring). Said another way, the nations were not contributing funds to buy a capability to be used by NATO military commanders if and when the North Atlantic Council provided a mandate to do so.

- c) The USAF committed to provide operational experience and Boeing provided maintenance experience that allowed immediate payback to the contributing nations. Within a few weeks of accepting delivery of the first C-17, the USAF dominated Heavy Airlift Wing began flying missions to Afghanistan.

In my opinion AGS has floundered because:

- a) Although the Global Hawk was was a mature unmanned aerial system (UAS), and so available off-the-shelf, the radar system to be installed on the GH was still in development, and the European partners insisted that ground stations be newly developed so as to enlarge the European technology base and provide industrial participation opportunities (jobs) in Europe.
- b) b) As nations defected from the AGS Program, available funding decreased and the original vision for the UAS version of AGS became unaffordable.
- c) c) As Northrop Grumman reduced capabilities to make AGS affordable, the contract was delayed, industrial participation opportunities became less attractive, the predicted outcome was less attractive to the NATO military commanders, European economies reached a crisis, and political will to see the AGS program to completion declined.

Now, to answer your question at long last, it is my opinion that experience transfers more effectively when the acquisition concerns [1] military off-the-shelf items, [2] that nation's need for national purposes, [3] that will become operational in a short period of time, [4] that do not involve dynamic contract requirements, and [5] are limited to nations that want to participate rather than feel "trapped" into participating in order to meet political commitments.



*Response II:* I think there is a big difference between the aircraft types when it comes to combined operations. While it is possible to have combined operations for a transport aircraft used for supply or humanitarian purposes after agreeing to rule sets regarding a nation's ability to opt out of a mission, liability responsibility, and the like – the degree of difficulty of having combined operations for an offensive capability like a fighter is significantly higher. It would be difficult to avoid the situation where all 28 members of NATO would have to agree on the use of lethal force. The existing NATO AWACS and the planned AGS are information collectors and have not set precedents in this area.

3. What role can or have the contracting firms play(ed) in adjusting to lessons learned between successive projects – Boeing, for example, in its experience with NATO AWACS and NATO Strategic Airlift Capability?

*Response I:* The contractors' role is huge. In the earliest days, nations will be reluctant to sign letters of intent unless they understand the concept and trust that the contractor can deliver within the estimated cost. As you suggest, Boeing is a great example. Boeing's marketing staff provided an outline for the SAC Project and, even though we ultimately took a different procurement approach, Boeing personnel were gifted educators and innovative financiers for those nations that needed (or thought they needed) bridge funding in the early years until their financial programming produced sufficient appropriations. Boeing offered the shared spare engines and parts pool in the form of Globemaster III Sustainment Partnership that kept initial cost and life-cycle costs at a reasonable level. Boeing brought this concept (and their lessons learned) to the (Strategic Airlift Capability program) from previous international C-17 customers (AUS, CAN, UK), and Boeing took the lessons learned on the road to Qatar, UAE, and India.

Lockheed Martin does pretty much the same thing to market its C-130Js and is a necessary partner in the C-130J Joint User Group that has been so successful at defining and fielding new requirements and capabilities for that weapon system. I am sure it appears incestuous to those that are protected by



healthy suspicion, but that kind of industry ([featuring] customer 1-customer 2-customer 3) cooperation is extremely important to promote capability advancement, maintain common configurations, simplify airworthiness certification, enhance aviation safety, increase interoperability, increase operational readiness, reduce risk of diminishing manufacturing sources, and thus reduce life-cycle costs for the US and its international partners.

*Response II:* AWACS and Strategic Airlift Capability are separated by 25 years and we did not see that Boeing people ... drawing upon AWACS experience; the governments brought the AWACS lessons learned to the Strategic Airlift Capability program. At the onset of the C-17 program, I expect that the AWACS consortium knowledge was brought into play by Boeing as they had been marketing the program to individual nations and NATO as a whole for a long time without getting traction. An AWACS-like consortium was the only way to penetrate the market. After the nations signed the Letter of Intent expressing interest in buying C-17s it was the governments, primarily the USAF, who structured the details of the program after examining other programs.

4. What role can or has the US service branch handling the FMS acquisition play(ed) in adjusting to lessons learned? The impressive role played by the U.S. Navy in serving as something of a "mother hen" in establishing (with Boeing) an F/A-18 user community. Among other things, NAVAIR served as intermediary between the users and those agencies charged with enforcing US arms export control and technology transfer regulations – acquiring a blanket approval, for example, for the transfer of non-confidential items between users. In general, NAVAIR served to moderate bureaucratic obstacles to the smooth handling of logistic and maintenance issues. Does the US Air Force play a similar role in the C-17 community and, were there evidences of something like it in the F-16 experience?

*Response I:* The (Navy) example you provided above is a good one. I think the military departments all aspire to provide the same level of service and support to FMS customers and, from the anecdotal evidence that has come to my attention, I would say the USAF generally meets its aspirations. Certainly, the C-17 Security Assistance Program Office [SAPO] has a mature process that has





minimized the effect of the Arms Export Control Act on C-17 sales and support for the several international operators. The Security Assistance Program Manager [SAPM] has opened an area in the SAPO area where Strategic Airlift Capability and each of the international C-17 user nations assign liaison officers to share program lessons learned ranging from tech orders to accident reports. That model provides a lot of confidence to international partners and thereby promotes international cooperation.

Response II: I think that all of these major programs have benefitted from a strong service program office and prime contractor relationship. This kind of teaming is critical on international programs and I think the government and contractor have far more objectives in common than there are differences. The C-17 program followed the same F/A-18 blanket third party transfer approach to enable spares sharing and the program office worked hand in hand with Boeing to establish the Globemaster Sustainment Program where all purchasers paid funds to create a Boeing held spares pool – this made the C-17 sustainment affordable to countries with small fleet sizes. When you get into these type of multilateral undertakings the program office and contractor relationship needs to be very close, On the F-16 program, in many respects there was far less multilateral cooperation after program initiation – more bilateral cooperation than what we have seen on the NATO programs and in C-17 sustainment activities. The original F-16 participants did cooperate in the funding of upgrades but I did not see much multilateral logistics cooperation.

5. More broadly, does your own experience in the F-16 and F-35 programs yield any sign of transfer of lessons learned in building organizational structure and/or establishing operational procedures?

*Response I:* When the JSF international program was structured it was done with the knowledge of the F-16 program practices. Again, these programs were separated by around 25 years and good ideas in the late '70s are not always good ideas now. So the lessons learned were transferred and some were adopted but many did not fit the JSF program. I think this is the case that we find





in structuring all major international programs – the people developing the program structure investigate similar programs to determine how they addressed issues, learn from the dialog, and then establish management practices that meet the needs of the new program – and hopefully we are getting better at this over time.

6. Moving beyond a narrow focus on NATO acquisitions, Boeing persons have spoken proudly of their success in structuring an all-inclusive user community, whose members can depend on a worldwide seamless system to meet all logistic and/or maintenance needs – without distinction based on details of purchase or organizational attachment. On its side of the table, so to speak, has the US service branch involved been equally enthusiastic about pursuing this goal, say the Air Force in its role in support of NATO C-17 or does the possibility of divided loyalties sometimes arise, on occasion where NATO Strategic Airlift Capability interests appear to conflict with broader interests of USAF?

*Response I:* I am confident that the USAF is equally enthusiastic about pursuing this goal, because we do so for selfish reasons tied mostly but not entirely to money. (Aside from economies of scale) FMS is entirely customer funded, so the SAPO employees have a personal interest in making FMS cases work and to generate new business for future job security. From the burden sharing perspective, all levels from the operational transport commanders to the President want our allies to be interoperable with the US; support NATO forces in Afghanistan with their own aircraft – buy American. And sometimes we look to our partners to create capabilities for us to use. There are several examples of this in respect to space surveillance, satellite communication, GPS, and search and rescue capabilities...In the end, the USAF is saving billions of dollars achieving necessary but otherwise unfunded capabilities for our warfighters, with the side benefit of contributing a substantial amount to the US balance of international payments.

*Response II:* The USAF has been an enthusiastic supporter of the Globemaster Sustainment Program and the multinational logistics aspects, and has worked many policy issues within the USAF and the State Department to make the



program even more effective. The USAF obtained benefits from the enhanced spares pool and the relationship with the Brits, Aussies, and Canadians (initial C-17 purchasers) that were very important to the USAF and strongly supported by USAF leadership. While the USAF would likely not have created the NATO C-17 program on its own, after DEPSECDEF directed the USAF to do it – there was strong support in all quarters and the USAF has held this program up as a model example of building partnership capability.

*Response III:* The United States Air Force encourages individual programs to find unique best value logistics solutions within the guidance and constraints of policy and law. The C-17 program office feels that it can deliver the best value for dollar for the C-17 operating community by pooling the world-wide C-17 requirement rather than as a series of stove-piped logistic efforts. This is effective because of broad consensus on the desired logistics outcomes. However there is nothing in the C-17 arrangement that limits a national-level operator from buying additional services or operating their fleet of C-17 independently from this virtual fleet construct. Were national level operators' logistics requirements or interests to diverge greatly from that of the consensus position we would need to structure a different logistics arrangement for them. The C-17 virtual fleet works because the non-USAF nations have determined they can live with the logistical outcomes for which the USAF strives.

As the operator of over 80% of the global C-17 fleet, the USAF logistics outcomes for C-17 sustainment dominate our thinking and arrangements. Currently the USAF has established sustainment outcomes at or above those desired by the other virtual fleet partners. We believe we can sustain a viable virtual fleet arrangement as long as the USAF requires sustainment outcomes near or above those of the remaining virtual fleet partners – should it desire extremely low outcomes, this would pose a problem. Historically, the USAF has never requested levels of service low enough to threaten the viability of the virtual fleet model.



7. Certain major players in the early days of the NATO C-17 story have expressed the belief that the structure and operational arrangements of that program might serve as a model for multinational acquisitions in other regions where individual nations find separate purchases of equipment too expensive to consider. Do you agree with that view or, is it likely that the success of the NATO C-17 program was due to factors that were region- and/or circumstance specific and thus, less likely to be easily duplicated elsewhere?

*Response I:* I do agree, but the Strategic Airlift Capability model is not one-size fits all. Some in DoD and the State Department tried to use it to improve tactical (not C-17) airlift capabilities in Africa. It didn't work for several reasons, the most notable that African partners couldn't afford to contribute, the composition of the African Union (intended by some to serve the role of NATO when it took ownership of the aircraft) was not acceptable under US export controls, and the environmental and social-political conditions in "Africa" did not reconcile with the (European C-17) concept. Africa is just too large, too diverse, and generally under-capitalized. Strategic Airlift Capability is a tool to be used with greater precision.

On the other hand, we used a (similar) process for the US to partner with Canada, Denmark, Luxembourg, and Netherlands to add a \$500M Wideband Global Satcom (WGS) space vehicle into the US WGS constellation; we went operational this past January and it is working extremely well. We are running similar bilateral space projects that are also working well.

I think you and I discussed Acquisition Cross Service Agreements (ACSA) as authorized in Title 10 USC. Wine, but in a different bottle. Before we kicked off WGS, the [participants] needed to calibrate their ground stations. US forces could have helped them via Foreign Military Sales [FMS] but there wasn't time to exercise the FMS process. Instead we wrote implementing arrangements under the existing ACSA and completed the calibration with plenty of time to spare.



NATO is now subscribing to "Smart Defense" and "Connected Nations." From the perspective of creating military capabilities, the USAF has long been in that mode.

*Response II:* The C-17 program leveraged the "legal personality" of NATO enabling the NATO Airlift Management Agency to purchase the aircraft, sustainment, and training from the US Government through FMS. While NATO is not involved in the operational aspects of the program act, across the program as a whole NATO provided the glue to keep the program together. NATO provides a legal entity to do the contracting. NATO was a recognized international organization with security agreements with the US such that the US has the authority to export defense articles and services.

I think it is possible for a SAC- like program to be done on other programs and in other regions on defensive systems or intel collectors in other regions, but it will be more complicated and you would probably need a lead nation approach like being used for JSF acquisition.

*Response III:* What makes strategic airlift well suited for a consortium arrangement is the fungibility of the operational impact. Strategic airlift success is often measured in the delivery of a single aircraft load of cargo. The ability to buy in to a "ton-mile" arrangement allows nations with small requirements to pay small sums. Additionally, the international system is more permissive with the movement of unarmed aircraft flying cargo between world hot spots than it would be of consortium members "sharing" attack aircraft and attempting to ferry them between geographically separate military conflicts. I am skeptical that a consortium arrangement can be worked outside the airlift mission area.



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### III. T-X Trainer Program

The U.S. Air Force (USAF) is planning to replace the venerable T-38 Talon jet trainer. The program to do this, formally the Advanced Pilot Training Family of Systems, is also known by the acronym “T-X.” The USAF published a Request for Information (RFI) in March of 2009, contemplating a family of systems, to include about 350 aircraft, simulators, and training infrastructure. However, at the time of writing, no Request for Proposals (RFP) has been released.

Alenia executive Alessandro Franzoni has claimed that the USAF desires a “non-experimental platform,” which would imply a U.S. prime contractor in partnership with a foreign manufacturer of an existing jet trainer (Morrison, 2011). However, the RFI is more generic:

This RFI is a continuation of a market research effort being conducted by Aeronautical Systems Center to collect information on high-performance, two-seat military jet trainer aircraft and ground-based training systems to include full-fidelity simulators, courseware and other virtual/computer based training applications. These elements should be presented as a Family of Systems (FoS) that facilitate the accomplishment of the objectives of the USAF Advanced Pilot Training Fighter/Bomber Track including the Introduction to Fighter Fundamentals Course. There are five fighter flying training requirements that lend themselves to two-seat instruction prior to performing them solo: sustained high-G operations, air-refueling, night vision imaging systems operations, air-to-air intercepts, and data-link operations; any submitted FoS should be capable of performing all of these functions plus all other required syllabus events. Note: The aircraft itself does not necessarily have to be capable of all functions; for example the air refueling could be accomplished in a full-fidelity simulator (U.S. Air Force, 2010).

The Commander of Air Education and Training Command (AETC), General Edward Rice, has stated that replacing the T-38 is “not urgent,” and that the Talon can be flown “into the foreseeable future” (Majumdar, 2011). However, T-38 maintenance, supply, safety and failure concerns will increase as the T-X program is delayed (Butler, 2011b). While introduction of the F-22 Raptor and the F-35 Lightning II Joint Strike Fighter into the USAF inventory will make T-38C training less useful (at least as a lead-in for the F-22 and F-35), a new training aircraft remains a low priority in a tight budget



environment. As Amy Butler of *Aviation Week*, a well-known industry observer commented:

The T-38C, which is a lead-in trainer for fighter pilots, continues to operate without restrictions despite an average age of well more than 40 years. The Air Force has a careful balancing act ahead, as officials weigh how late they can start a competition for the T-X and field a new aircraft against the pitfalls of continuing to maintain a fleet that is costing increasingly more to operate (Butler, 2011a).

Butler noted a few months later that the Air Force had “punted” on its T-X plans, with the President’s Budget for Fiscal Year 2013 pushing initial operational capability from 2017 to 2020 (Butler, 2012a). Our review of the T-X program takes place at a very early stage in the project, with the development, manufacturing and delivery of the system a decade or more away.

We begin this chapter with a discussion of the T-38C Talon, the aircraft that the T-X would replace. We next review the competitors for the T-X prime contract that responded to the RFI. Finally, we will provide some comments about the challenges facing this major program.

#### A. The T-38C Talon

The Northrop Grumman T-38C Talon currently serves as the USAF’s primary jet trainer. The first production aircraft were delivered in 1961. Production ended in 1972, and over 500 remain in the USAF inventory. The trainer has been updated over its fifty years of service to include a glass cockpit and increased thrust from its twin J85-GE-5 turbojet engines. Supersonic maneuvers can be practiced at a maximum level speed of above Mach 1.2 at 36,000 feet. Graduates of T-38C training go on to fly the F-15 Eagle, F-16 Fighting Falcon, A-10 Thunderbolt II (or “Warthog”), F-22 Raptor, and other aircraft.

The Talon features ease of maintenance, with critical components accessible at waist height. The National Aeronautics and Space Administration, the Turkish Air Force, and the U.S. Navy (USN) also operate small fleets of the T-38C. The T-38C will



also be used for future pilots transitioning to the F-35 Lightning II Joint Strike Fighter, with training for all F-35 variants at Eglin Air Force Base, Florida (Lockheed Martin, 2012).

With ongoing life extensions, T-38 retirement is currently forecast for 2020 (U.S. Air Force, 2008; Hunter, 2011). However, there have been reliability and safety concerns with the current upgrade of the T-38C, three aircraft being lost in crashes in 2008 and 2009. The USAF decided to accelerate the replacement process, from the original RFP issue goal of February or March 2011, and a T-38C retirement goal of 2017. However, budget priorities and the relative longevity of the T-38C have led to postponement of the release of an RFP for the T-X. The most recent detailed budget data shows an anticipated cost of \$15.9 billion for the T-X program, in Fiscal Year 2012 dollars (U.S. Department of Defense, 2011).

#### B. A “Fifth-Generation” Trainer?

A key factor in the development of the T-X is the decision not to develop two-seat versions of either the F-22 or the F-35. In the case of the F-22, a RAND study found that the lack of a two-seater created “inherent safety concerns” (Ausink et al., 2011). This safety deficiency results in part from the fact that pilots must progress directly from an old, although upgraded, twin-seat T-38 first delivered in 1961 directly to a single-seat “fifth-generation” fighter replete with sensor systems and designed to operate in a heavily networked environment.

With a two-seater version of the F-22 or F-35, the inevitably long process of delivering the T-X would pose fewer problems for F-35 pilot training. While AETC was able to develop a satisfactory lead-in training program for the single-seat F-22 using a “bridge course” of eight flights in the F-16, the same workaround may not be possible with the F-35 (Butler, 2011b). The reasons include an overload of learning tasks, due to the numerous capabilities of the F-35 that cannot be replicated with a combination of T-38C live flying and F-35 simulator flights (Lafortune, 2010). There is also an emerging recognition of the desirability of a common approach to lead-in training among the JSF partner nations:





If the Air Force opts to begin the T-X sooner rather than later, there could be an unprecedented and unintended effect for the winning contractor team. The international coalition knitted together to develop and buy the F-35 could unify the Joint Strike Fighter nations that have yet to commit to a new trainer around a more like-minded approach based on the USAF decision. This could allow partners to capitalize on economies of scale and ensure uniformity for training pilots headed for service in the F-35. One interesting dynamic, however, is that two of three expected T-X bidders are from F-35 nations already embarking on new fast-jet training programs: Italy, buying the Aermacchi M-346, and the U.K., purchasing the BAE Systems Hawk Mk. 128 (Butler, 2011b).

The technological changes in undergraduate jet training discussed above have resulted in a shift in thinking as to multinational cooperation in earlier stages of pilot education. This emerging trend is motivated by the need for future fast-jet trainers to represent the key features of the F-35, or eventual equivalents, with a corresponding shift among the stages of training:

The key difference between a fourth- and a fifth-generation fighter training system is that pilots need to be taught primarily how to fly in preparation for fourth-generation assignments. For aircraft such as the F-35 or F-22 the desired outcome is managing operations—with the pilot processing and then acting correctly on the large amounts of mission-critical information being relayed from onboard and remote sensors.

“In fifth-generation fighters, flying will be easier, and the flying skills will be dealt with earlier in the training program,” says Paul Dawkins, head of business development, air training, at BAE Systems. “The systems will look after the aircraft and reduce the flying workload on the pilot.” Instead, the training system will focus on ensuring the pilot can optimize the automated tools available, concentrating on the overall mission requirements. Winning the T-X contest therefore may not depend on the performance of the trainer aircraft but the way real and synthetic training are integrated, allowing for the most comprehensive and realistic training of fifth-generation fighter capabilities at the lowest through-life costs (Butterworth-Hayes, 2012).



The F-35 program is a U.S.-led collaboration, with the UK as the only Level 1 partner.<sup>10</sup> BAE is both the largest UK defense firm and the principal British participant in the F-35 team. BAE's interest in the T-X program therefore makes strong business sense (Joint Strike Fighter Program Executive Office, 2012).

Four firms or teams have announced that they plan to bid on the T-X, led respectively by BAE Systems, Alenia, Boeing, and Lockheed Martin. We will discuss the highlights of each proposed bid in the following sections.

### **1. The Alenia M-346**

The Alenia Aermacchi (Alenia) M-346 Master first flew in 2005. Customers include Israel, Italy, Singapore, and the United Arab Emirates. Interestingly, the original model was based on the Russian Yak-130. Initial certification from the Italian Ministry of Defence was received in June 2011. For the purposes of the T-X program, Alenia has designated the M-346 as the centerpiece of the "T-100 Integrated Training System." Another proposed T-100 participant would be Alenia's sister firm and Finmeccanica U.S. subsidiary DRS Technologies, which has considerable expertise in systems integration. The M-346's twin Honeywell F-124 engines would be manufactured in Phoenix (Alenia North America, 2012; Butler, 2011b; Hunter, 2011).

In February 2012, the Israeli Air Force announced it had selected the M-346, with a stated requirement of twenty aircraft. The M-346 will replace the IAF fleet of Douglas TA-4J Skyhawks (Hunter, 2011). Alenia management has publicly stated that they wish to have a U.S. partner for the T-X program (Downs, 2010). With Lockheed Martin and Northrop Grumman having already selected foreign partners, Boeing would be a likely choice, as discussed in the section on Boeing below.

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<sup>10</sup> Chapter IV below discusses levels of partnership in the F-35 program.



## **2. The BAE Hawk**

The U.S. Navy already flies a variant of the BAE Systems Hawk, as the T-45 Goshawk jet pilot trainer, with 221 aircraft delivered from 1988 to 2009 in a collaboration with McDonnell Douglas and later Boeing. The Goshawk has its origins in the replacement of its naval predecessor, the TA-4J Skyhawk. The USAF was initially interested in a joint procurement with the USN of an undergraduate jet trainer to replace the T-38, but later withdrew from the T-45 program (Boeing, 2012; Higham, 1987; Jackson, 2011a).

In the anticipated T-X competition, BAE proposes to team with Northrop Grumman (NG), with BAE acting as prime contractor, and offer the Hawk T2/Mk128, also known as the Hawk AJT (Advanced Jet Trainer). Northrop Grumman would manufacture the aircraft, perhaps with final assembly at its Lake Charles, Louisiana plant. L-3 Link Simulation and Training has signed an agreement with BAE to provide ground-based training and simulation (BAE, Northrop Grumman, partner 2011; Butler, 2011a; Butterworth-Hayes, 2012).

While any potential USAF version will be different from existing models, the RAF and the air forces of Australia, Bahrain, Canada, India, and South Africa currently operate the Hawk. BAE contends that the Hawk AJT was designed to provide training for future pilots of both fourth- and fifth-generation aircraft (BAE Systems, 2012).

The UK's Royal Navy (RN) does not currently have any fixed-wing carrier-based aircraft. There has therefore been no need for a trainer similar to the Goshawk. The decision (since reversed with a return to the F-35B STOVL version) to procure the F-35C carrier variant of the Joint Strike Fighter for the upcoming Queen Elizabeth (QE) class carriers raised the issue of lead-in training for the F-35C. Conceptually, RN acquisition of a BAE Hawk variant for carrier training appeared logical from the requirements and industrial policy perspectives, particularly given the need to integrate training and operations with other UK and US services. The UK expects to acquire 70 F-35s, which will serve both the RAF and RN (House of Commons Committee of Public Accounts, 2011; Jane's, 2012a).



BAE and NG are subcontractors to Lockheed Martin on the F-35 program, and Australia, Canada, and the UK fly the Hawk as well as being participants in the F-35 collaboration (Joint Strike Fighter Program Executive Office, 2012; Jackson, 2011d). If the USAF were to procure the Hawk as the centerpiece of the T-X program, there might be significant benefits to jet training through systems integration and technology transfer between the Hawk and F-35. As discussed previously, any future jet trainer will need to be representative of F-35 pilot skills, but the Hawk would offer an integrated multinational consortium for both jet training and fighter operations.

The choice of the Hawk could be excellent for the USAF, as RAND (Ausink et al., 2011) expressed serious concerns about the ability of AFMC (Air Force Materiel Command) and AETC to develop and maintain the sophisticated family of systems required to support initial and ongoing training on fifth-generation fighters. The RAND study also noted the following challenges related to current F-22 Raptor pilot training:

For the following three reasons, the RAND study concludes that there is strong evidence for a training gap as a significant issue.

1. Inexperienced F-22 pilots are currently accomplishing only six or seven live sorties per month. They are unable to achieve RAP [Ready Aircrew Program] training minimums.
2. F-22 respondents to the ACC [Air Combat Command] survey indicate the need for an increase in both live and simulator training, as well as a change in the distribution of mission categories flown.
3. Preliminary MEC [mission essential competencies] analyses show that there are existing and potential gaps between experiences that F-22 pilots need to have and what they are able to receive. (Ausink et al, 2011, p. xii).

If JSF-like performance were a key goal for the T-X family of systems, a Hawk-based training system that includes Australia, Canada, and the UK, all of whom have experience using current versions of the Hawk, may provide an attractive way of mitigating the obstacles associated with the development of a family of training systems suitable for fifth-generation fighter lead-in.



### **3. Boeing**

In June 2011, Boeing announced a completely new aircraft design as its offering in the T-X competition. The rationale provided was that the USAF was still at the analysis of alternatives stage. Therefore, Boeing wished to keep its options open, including a new aircraft – pursuing “a concept for a purpose-built trainer, featuring a V-tail and a single engine” (Trimble, 2012).

In September 2011, Boeing released an artist’s rendering of a proposed T-X submission. The firm described as a “concept” a single-engine aircraft featuring a V-tail with a wing-platform, similar to the Northrop-McDonnell Douglas YF-23 prototype fighter that was Boeing’s entry into the Advanced Tactical Fighter competition, which was decided in favor of the Lockheed Martin F-22 Raptor (Melenic, 2011).

Boeing indeed appears to be keeping its options open. The Alenia M-346 currently lacks a U.S. prime contractor partner for the T-X program. However, Boeing has teamed with Alenia under Singapore Technologies Aerospace to provide an M-346 training system to the Singapore Air Force. Boeing’s response to an eventual RFP might possibly feature the Alenia M-346 rather than a newly designed aircraft (Butler, 2011b).

Industrial policy could also play a role in the selection of the T-X prime contractor. With Lockheed Martin having won both the F-22 and F-35 competitions, and with continuing export sales and upgrades of the F-16 Falcon, there is a possibility of the U.S. ending up with a single manufacturer of combat aircraft. Boeing is limited to export sales of the aging F-15 Eagle as well as producing the contemporary F/A-18E/F Super Hornet for the USN. Additionally, the USN buys the EA-18G Growler electronic warfare variant.

Should Boeing win the T-X competition either with an original in-house product, or by teaming with a foreign partner such as Alenia (which currently lacks a U.S. partner for its M-346 offering), the resulting major contract could ensure Boeing’s long-term presence as a combat jet manufacturer. If the USAF selects the Lockheed Martin/KAI



T-50 Golden Eagle for the T-X, economic, political, and industrial base concerns may make the decision very controversial.

Finally, a win for the BAE Systems/NG Hawk might serve to re-establish NG as a prime contractor for fighters, a role it gave up with the failure of the F-20 Tigershark (originally designated F-5G) in 1986, and later with the loss of the JSF competition to Lockheed Martin in 1991 (Yoshihashi, 1986; Lambert, 1991).

#### **4. Lockheed Martin**

Lockheed Martin and Korea Aerospace Industries (KAI) jointly developed the T-50 Golden Eagle during the 1990s. The Republic of Korea Air Force (ROKAF) received fifty of the original model, with the last delivery in 2010. The Golden Eagle is powered by one GE F404 turbofan, the same basic engine used (in pairs) on the Boeing F/A-18A through D models. The sole current export customer is Indonesia, which announced a contract for 16 T/A-50s in May 2011. (Jackson, 2011c; Trimble, 2011).

The fact that LM already produces the F-22 and F-35 could be seen as a strong technological advantage as well as a major political burden. We have already discussed the narrowing gap between “trainers” and fifth-generation combat aircraft. An informed observer could be skeptical of the possibility of the U.S. Department of Defense awarding a third major combat aircraft production contract to LM. Supporters of Boeing, BAE, and Northrop Grumman would strongly object to a T-50 selection, to say the least. The Asian, rather than European, origin of the technology could also be a concern. Such a decision would inevitably be spun as the end of the competitive fighter industry, making LM to fighters what Huntington Ingalls Industries is to aircraft carriers: the sole domestic supplier.

#### **C. Conclusion**

Three considerations will likely influence the outcome of the T-X program. The first is the challenge of coherently specifying the requirements for a jet trainer, and then delivering the aircraft and associated systems in sufficient quantity and at a cost that



does not result in cancelation of the program, or acquisition of such a small fleet of aircraft that their use is not viable.

The second consideration is whether the Air Force can successfully integrate potentially useful foreign technology without imposing national requirements that destroy the benefits originally sought from acquisition of an existing (but “Americanized”) system. Third, the development of the aircraft and associated systems must remain focused on the primary jet trainer role. Pilots will continue to require acquisition of the necessary expertise to progress to the wide variety of fighters and bombers flown by the USAF.

The T-X program may take on some characteristics of a fifth generation-compatible trainer. If that occurs, the project may collapse under its own weight, as previously suggested. The active participation of close allies, such as that suggested by the BAE/Northrop Grumman Hawk, may serve to moderate the more technically aggressive tendencies of USAF procurement.

However, controversy may emerge over how many fighter manufacturers, assemblers, or system integrators the U.S. requires. Lockheed Martin’s current production of the F-16, F-22 and F-35 already puts that firm in a quasi-monopolistic role. Boeing will continue to exploit the F/A-18 and its derivatives for the next ten to twenty years, but clouds are already emerging on the horizon. The selection of the BAE Hawk would lead to Northrop Grumman assembling fighters for the first time since the F-5 and F-14.

The rapidly evolving role of unmanned aircraft will also become an important industrial policy consideration, not just from the perspective of “replacing” manned aircraft, but also given the need to provide highly integrated, networked architectures among services and coalition partners for manned and unmanned aircraft training and operations.

The challenges associated with the T-X program may be comparable to those experienced with the F-35. A successful outcome for the USAF Advanced Pilot Training



Family of Systems program will likely depend on the ability of all parties to show genuine restraint in formulating requirements, as well as excellent program and technology management.





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## IV. The F-35 Program and Governmental Politics<sup>11</sup>

The F-35 Lightning II, the newest US fighter aircraft, is the largest procurement project for the Department of Defense (DoD). Developers of the aircraft have promised that it will significantly advance fighter operational capability in an aircraft that is relatively inexpensive to maintain. The current DoD plans call for a total of 2,443 F-35s, also called the Joint Strike Fighter (JSF), for the Air Force, Navy, and Marine Corps -- plus hundreds more going to US allies. The estimated cost of acquiring the JSF for US customers continues to change; as of 31 December 2010, it was estimated at \$271 billion in FY2002 dollars (Gertler, 2012, p. 11) -- and continues to increase.<sup>12</sup> Recently the program has made headlines because of its rapid increase in cost from \$69 million per aircraft to \$133 million in 2011 (Sullivan, 2012). This paper will discuss the history of the JSF Program and will identify the key players and their interactions while procuring this new airframe.

### A. Program History

The Joint Strike Fighter (JSF) Program's original vision was an affordable family of next-generation strike fighters for all branches of the government (Aboulafia, 2012, pp. 7-8; Blickstein, et al., 2011, pp. 35-36).

Each branch of the armed services needs aircraft to perform different missions that are central to their various global missions, and the F-35 needs to fulfill all of these requirements. To do this, three variants of the aircraft are being developed for the Air Force, Marine Corps, and Navy all with different landing capabilities. Specifically the

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<sup>11</sup> The primary author of this chapter is Cadet First Class Holden Simmonds, USAF Academy, Class of 2013. His work was accomplished with NPS sponsorship under the auspices of the Academy's Cadet Summer Research Program

<sup>12</sup> The problem of tracking just how much F-35 program costs have increased turns out to be complicated, and made more difficult by what one observer calls "rubber baselines" as points of comparison (Wheeler, 2012).



Navy will get a fighter that can land on a carrier, and the Marine Corps will get a short takeoff vertical landing (STOVL) model. The vision of the JSF Program is to be the “model acquisition program for Joint service and international cooperation” while developing an affordable strike fighter and that can be successfully sustained worldwide (Book, 2003). Throughout the development and acquisition process all US services and other countries had a role in its development.

## **1. History**

In 1993 the United States Department of Defense (DoD) accomplished a Bottom-Up Review (Aspin, 1993) of U.S. Military forces. The purpose was to identify a new defense strategy for the post-Cold War era and address a number of issues including force modernization done affordably. The Joint Strike Fighter program sprang from this effort and was originally called the Joint Advanced Strike Technology (JAST) Program. The board determined that it was time to produce a common fighter aircraft that could be used in the different branches of the military. It was believed that by doing this the United States would save money because training and aircraft maintenance would be largely universal (F-35 Joint Strike Fighter (JSF) Lightning II Program, 1996-2003, 2012).

Major points of emphasis for the JAST program were affordability in terms of acquisition and operations throughout the life cycle. For this reason it was believed that having common parts between the different versions would limit the cost to maintain them (Aboulafia, 2012, p. 8).

In December 1994 the Concept Exploration (CE) Phase was completed. This phase focused on exploring new concepts and technologies that could develop a cost efficient airframe that can still accomplish the mission. Two decisions central to the JAST program were made during this phase: designing with a single crew and a single engine. This rationale was saving money, in both acquisition and operating costs (Arnold, 2010, p. 2; Blickstein et al., 2011, p. 35).



After the completion of the CE Phase, Boeing, Lockheed Martin, McDonnell Douglas, and Northrop Grumman were awarded fifteen-month Concept Definition & Design Research (CDDR) contracts to develop the following:

- Specific weapon system designs based on a tri-service family of aircraft
- Risk reduction plans for the transition of critical technologies into the EMD phase with low technical risk, and moderate integration risk. (Arnold, 2010,p. 1)

In November 1996 the CDDR Phase was completed, and the US government awarded Boeing and Lockheed Martin the rights to both build and test fly their aircraft. The government closely monitored their work in developing these jets. In March 2000 the Joint Operational Requirements Document (JORD) was signed (Aboulafia, 2012, p. 8).

In October 2001, after both Lockheed Martin (XF-35) and Boeing (XF-32) demonstrated their capabilities, the F-35 was assessed as being better. Accordingly, Lockheed Martin was chosen to develop and produce the Joint Strike Fighter (Gertler, 2011). The F-35A completed its first flight in 2006, and by June 2010 the B and C models both completed their first flights, including the first demonstration of the hovering ability in the STOVL (Gertler, 2011).

However, the F-35 development program was plagued with a number of difficulties (described, for example, in Blickstein, et al., 2011). And, on 26 March 2010 - the Air Force notified OSD and Congress of a second Nunn-McCurdy breach in the JSF program (Sullivan, 2012). According to the Nunn-McCurdy Amendment, when a Major Defense Acquisition Program (MDAP) experiences an increase of 15% requires unit cost, reporting is required (Nunn-McCurdy Amendment, 2012). Further, when any MDAP goes above 25%, then a SECDEF certification must be obtained. In order to meet the requirements for certification it must be shown that the project is crucial to national security, that there are no other alternatives to the current project, and that steps have been taken to mitigate the increase in cost (Blickstein et. al., 2011).

Accordingly the following steps were taken.



- On 23 Sept, 2010 the United States agreed to a fixed-price incentive fee contract for the purchase of 30 F-35s that was 111 million dollars per unit. This meant that the U.S. would pay only 111 million dollars for the aircraft, and if developing them ending up being more expensive they reduce the number of aircraft purchased rather than spending more money (Gertler, 2011).
- In 2011 Pratt and Whitney F135 Engines exceeded all goals and demonstrated the maximum speed of 1.6 Mach (Venlet, 2012).
- On February 25th, 2011 the first production model of the Lockheed Martin F-35 Lightning II made its inaugural flight (Gertler, 2011).
- On 1 March, 2011 Commandant Gen. James Amos (USMC) personally vowed to oversee the production of the B model citing that it is vital to the future of the Corps after it is placed on probation by the Secretary of Defense (Watson, 2011).

## B. Current Issues

A DoD Report released in 2011 identified 13 areas in the F-35's development that could potentially be dangerous to cost or performance (F-35 Joint Strike Fighter Concurrency Quick Look Review, 2011). Despite the limited distribution of the report, those 13 areas were widely reported in the open press (e.g., Axe, 2011):

- Helmet-mounted display system not working properly.
- Fuel dump subsystem fire hazards present.
- Integrated power package unreliable and difficult to service.
- F-35C arresting hook not workable.
- Classified "survivability issues", which have been speculated to be about stealth.
- Wing buffet worse than previously reported.
- Airframe life likely less than required.
- Flight test program not yet progressed to the more difficult phases.
- The software development behind schedule.



- Danger of F-35B being overweight or not properly balanced for VSTOL operations.
- Multiple thermal management problems remaining.
- Automated logistics information system only partially developed.
- Lightning protection on the F-35 as yet uncertified, with remaining areas of concern.

In addition to engineering problems, the JSF continues to face other obstacles. In February 2012 it was revealed that cyberintrusions by China have been slowing down the process of developing the F-35. Examples of information that was breached include specialized communications and antenna arrays for stealth aircraft, as well as significant rewriting of software to protect systems vulnerable to hacking (Fulghum, et al., 2012).

From mid-2010 to mid-2012, cost estimates for the total program increased by nearly \$15 billion - to \$119 billion –an increase of over 40 percent since 2007. In addition to these increases, full-rate production has been delayed to enable further testing. As a result, when full scale production begins in what is currently scheduled for 2019, more money will be needed. Delaying procurement has been a trend for the past 3 years; and since 2002 total aircraft planned for purchase by 2017 has been reduced from 1,591 to 365.

One of the largest problems with the program stems from concurrency of JSF test and production lines. Doing all of these at once drives up both the testing costs and the acquisition price. Less aircraft are purchased because of the retrofitting costs associated with any technical problems found during testing. For example, in 2011 the JSF program paid approximately \$373 million to fix already purchased aircraft (Sullivan, 2012). Delaying purchase lessens risk, at least in the near term.

In 2011, 6 of the 11 primary testing objectives were met including the F-35B landing vertically on a ship and the F-35C (carrier version) completing static structural testing. However, the most challenging testing lay ahead. At that time, the flight tests had largely demonstrated “air worthiness, flying qualities, speed, altitude, and



maneuvering performance. “Areas needing more testing included “low altitude flight operations, weapons and mission systems integration, and high angle of attack” flight (Sullivan, 2012, p. 9). One major technical issue identified was the development of a total of over 24 million lines of code needed for the aircraft to be fully functional, more than 3 times the amount on the F-22. Again, concurrent development of the code is a major issue because postponing certain tasks until later means increasing chances that errors in programming will be made now (Sullivan, 2012).

In addition to these development delays, there is also a delivery rate issue. Currently it is taking a whole year extra to produce new JSF aircraft, although Lockheed Martin is working on ways to speed up the production line. Not all is bad for the JSF program because while it has become more expensive, it appears now to be on a more realistic path for success (Sullivan, 2012).

Nonetheless, prospects for rapid development are definitely not good. Accordingly, the total number of F-35's the U.S. will purchase will likely be adjusted downward by 179 aircraft in the near future (Sullivan, 2012).

Of all three versions of the aircraft the B variant is currently having the most difficulty. A severe bulkhead crack was one of five F-35B problems that emerged in 2011 F-35B that needed to be reengineered. This resulted in former Defense Secretary Robert Gates placing the aircraft development on probation in January 2011. If the aircraft development did not make significant progress by 2013 then he recommended that the B variant be canceled. . However, there is now some good news for the F-35B (Pike, 2011). On January 20th, 2012 Secretary Panetta removed the B Model's engine from its previous probation (Shanker, 2012)

### C. Model III (Governmental Politics)

Model III is one of three analytical tools used by Graham Allison to explain the Cuban Missile Crisis of the 1960's. Model III takes a broad approach to identify a myriad of factors that shape a given situation involving government action. At its base is the belief that public policy is the result of compromises made by officials who each have



their own diverse interests and power to affect a given situation (Allison & Zelikow, 1999, 294-295). According to Model III, analysis of given situation is framed by using the steps shown below.

- I. Organizing Concepts.
  - a. Who plays?
  - b. What Factors shape players' perceptions, preferences, and stands on the issue at hand?
  - c. What determines each player's impact on the results
  - d. What is the game?
- II. Dominant Inference Pattern
- III. General Propositions
  - a. Political Resultants
  - b. Action and intention
  - c. Problems and Solutions (Allison & Zelikow, 1999, Chap V, esp. pp. 296-297).

### **1. Organizing Concepts**

The first step in a Model III analysis is to identify all of the individual factors that affect a decision. Identifying the key players in positions of power and determining what factors shape those key players' decision making process is integral to understanding why things happen. Part of this is each player's individual and institutional priorities and perceptions. By understanding how they view the situations and looking at past experience it can be easier to identify their initial positions (Allison & Zelikow, 1999, pp. 296-297).

Goals and interests of the player also strongly influence their choices. For example, the U.S. Government cares a great deal about maintaining a good public image. This also goes with the stakes that each player has in a situation and how he or she takes a stand on that issue when considering all relevant factors. In addition, situation deadlines and how the issue is presented to the players factor into their decisions (Allison & Zelikow, 1999, pp. 298-299).

Defining the situation well is essential to understanding how people will respond to it. People notice different faces of the issue and deadlines affect the amount of time to make a well informed decision. Another key concept in identifying the relevant factors





in a situation is assessing the power differences among players, and where they get this power, and how well that power can be applied to the circumstances at hand.

“Bargaining advantages; skill and will in using bargaining advantages; and other players perceptions of the first two” play a huge role in who gets their way in a decision (Allison & Zelikow, 1999, p. 300).

Sources of bargaining advantages include “formal authority and responsibility: actual control over resources necessary to carry out action; expertise and control over information that enables one to define the problem, identify options, estimate feasibilities; control over information that enables chiefs to determine whether and in what form decisions are being implemented: the ability to affect players’ outcomes in other situations; personal persuasiveness with players who have bargaining advantages” (Allison & Zelikow, 1999, p. 300).

It’s also important to understand the rules of the particular game being played. There are understood (and “proper”) means by which the government gets its business done. Action-channels, or a “regularized means of taking governmental action on a specific kind of issue,” play a huge role in this. For example, U.S. ambassadors are an action channel for the president to deal with unfavorable events in another country. One also needs to understand the rules of the game, which include the relevant laws and customs, and well as the culture of the involved players (Allison & Zelikow, 1999, pp. 300-302). Government decisions are made through multiple players and their shared power. The environment that the game is played in, including its structure and pace, affect how each individual will use their power in a situation, and even after a decision is made, it may be implemented in a different way than anticipated (Allison & Zelikow, 1999), pp. 302-304).

## **2. General Propositions**

The rest of applying Model III involves analyzing how the players interact with each other within the rules of the game. The advantages and disadvantages for each player differ substantially from one action-channel to another, so that results between government decisions changes with respect to the situation. No given situation is



identical and most involve a different set of players. Most changes are created through games among players who see a situation differently and therefore treat it differently. Only rarely do all the players completely support the resulting decisions. Solutions to strategic problems come predominantly from the interaction of the players involved in reaching those solutions (Allison & Zelikow, 1999).

#### D. Model III and the JSF Program

There are far too many individual players involved in the JSF program to include all of them in this discussion, so we will identify and analyze the major : international partners, US Congress, Lockheed Martin, and the US military services (Air Force, Navy, and Marine Corps) – as discussed below.

International: There are four levels of participation for international partners that want to participate in the program. A Level I partner is fully collaborative and has the ability to influence requirements of the program (van de Vijver & Vos, 2007). Only the United Kingdom is at this level of participation (DiDomenico, 2006). A Level II partner is an associate and has limited ability to influence requirements (van de Vijver & Vos, 2007). At present, only the Netherlands and Italy commit this level of funds to the JSF program (DiDomenico, 2006).

Level III partners have no role in setting in aircraft requirements, but are updated on JSF Program developments so that they can decide (among other things) if they want to purchase the aircraft (van de Vijver & Vos, 2007). Countries in this category are Australia, Canada, Denmark, and Turkey (DiDomenico, 2006). The United States is the primary customer, and by far the largest participant in all aspects of the F-35 program.

Participant level is linked to financial commitment that country committed to procurement and development. Higher level participants have priority for JSF deliveries. Besides obtaining the new aircraft, being a participant in the research and development of the JSF also boosts the country's employment and creates connections within the aerospace field so a country can become further advanced technically. This is shown by



the projected 17,500-25,000 jobs that the JSF program will give to the Netherlands over the next 30 years (van de Vijver & Vos, 2007).

Lockheed Martin is one of the largest defense companies in the United States with 78% of revenue coming from military sales (Top 100, 2012). Since Lockheed Martin is a business, they need to make money. Accordingly, they want to keep the cost of the plane down while providing a good product. Moreover, they also incur penalties of various kinds for not performing as agreed. As Congress keeps lowering the numbers of aircraft purchased each year, Lockheed Martin's hopes of speeding up aircraft production to help lower per-unit prices are diminished. Nonetheless, Lockheed Martin will likely make money from this aircraft in the U.S. However, higher per-unit plan costs will probably decrease the number of aircraft they sell to allied nations with a lower defense budget (Laguerre & De Vore, 2011).

Congress: Congress has two bodies: House of Representatives and the Senate. Members of Congress are elected to enact laws and formulate policies for the nation. One of their major roles is to appropriate funds for government operations. A lot of different factors go into the final document, but one of the largest is the Defense Budget. Congress has tools at its disposal that help them ensure that money is not being misused. One of the more famous is the Internal Revenue Service better known as the IRS, but a lesser known one is the GAO or the Government Accountability Office. The GAO is nicknamed the "congressional watchdog" because it ensures that the government is not wasting taxpayer's dollars ("U.S. GAO"). The National Defense Authorization Act for FY 2010 requires the GAO to review the JSF program every year until 2016 (Sullivan, 2012). Congress's influence flows with the opinion of the people. At the beginning of the War on Terror Congress was much more inclined to spend money on Defense. But more recently, Congress has been much more concerned about the spiraling costs of the program.

The Department of Defense (DoD) consists of the Army, Navy, Marine Corps, Air Force, and civilian employees. According to the Department, "the mission of the DoD is to provide the military forces needed to deter war and to protect the security of our



country” (Mission Statement, 2012). The U.S. Navy has requested 480 survivable, carrier-based (CV) strike fighters to complement the F/A 18E/F, and they will receive the F-35C model (Lockheed Martin F-35 Lightning II, 2012). Unlike the Air Force with its many stealth aircraft, this aircraft would be the first operational Navy airplane designed for stealth characteristics. They are also particularly invested in the commonality of the F-35 because it would significantly lower the operating costs within the Department of the Navy (Gertler, 2011).

The US Air Force current request is for 1,763 “multirole, conventional take-off and landing (CTOL) aircraft to replace the F-16 and A-10, and complement the F-22,” and will receive the F-35A (Lockheed Martin F-35 Lightning II, 2012). The F-22 and the F-35 were designed to be compatible with one another, and the Air Force has said that each has unique capabilities, and complement each other when carrying out missions. The Air Force also believes that the 4th generation aircraft cannot survive long enough to operate and achieve the effects necessary to win in an integrated, anti-access environment (Gertler, 2011).

As of 2011, the Marine Corps requested 340 F-35Bs (STOVL) and a significant number of F-35Cs (carrier variant) to replace their Harriers and Hornets (Daniel, 2011). The Marines decided not to buy the F/A-18E/F Super Hornet, and are therefore in particular need of F-35s.

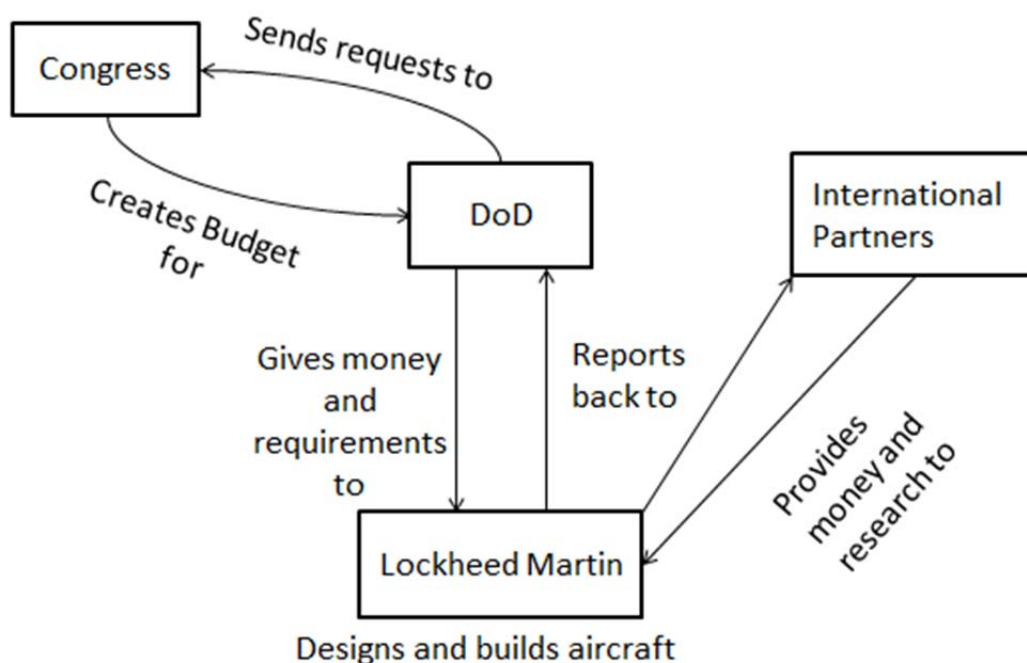
Aside from needing separate aircraft to fulfill different mission, each branch has their own other problems to worry about (Gertler, 2011). For example, the Air Force will need to budget between \$8 and \$11 billion per year for procurement of the JSF from 2016 through 2035 while developing and purchasing both the KC-46 tanker and a new stealth bomber (Sullivan, 2012).

## **1. Interactions: The Main Action Channel**

Figure 1 above shows broadly how these four players interact. There are, of course, many more factors that go into the decision making process. This is just a basic overview. Focusing on just the interactions from the American partners first, it is



apparent that the DoD has a central role. It acts as the middle man between Lockheed Martin and Congress. The DoD has a list of requirements for the new aircraft that is presented to Lockheed Martin. Lockheed Martin then returns an estimate to DoD of how much that will cost. The DoD then uses those numbers to come up with a realistic budget to send to Congress. Congress then meets and creates the real budget for the DoD who then distributes that money to Lockheed Martin. The International partners, based on their level of participation, contribute funds and research to Lockheed Martin. And, Level 1 and 2 partners make inputs regarding aircraft requirements alongside the DoD (Marrone, 2006).



**Figure 1. F-35 Action Channels**

Congress and the DoD work together to determine all parts of the defense budget, including the F-35. Every year the DoD must submit its portion of the President's Budget (PB) to Congress. Included in this bill are all items, both budgetary and nonbudgetary, that the DoD requests to be approved. This process is extremely involved and potentially includes all members of the DoD. The Department of Defense Office of Legislative Counsel (OLC) is in charge of unifying all DoD budget submissions

so that the document sent to Congress (via the President) is a united plan. Doing this requires a complex system of checks and balances where individual agencies are allowed to propose items to be included in the budget. Those items are then either accepted or rejected with opportunities for rebuttal or appeal (Marrone, 2006).

Once the OLC approves, the draft is sent to the Office of Management and Budget (OMB). The OMB then ensures that the bill is meeting the criteria within the President's agenda. Once that is settled, the bill then goes to the House of Representatives and the Senate for approval. Once there, they go to the House and Senate Armed Services Committees for deliberation. The Committees and their various subcommittees then analyze the bill and come up with a version that they feel they can approve. However, both the House and the Senate have to pass an identical bill, which rarely happens after the bills get out of the committees, so they meet again to work out a unified bill to pass (Marrone, 2006).

With all of this going on for the F-35 it is no surprise that the process was time consuming. For one thing, the F-35 is just a small part of a much larger bill – and subjects the program to annual changes (perhaps more frequently). Many individuals have to approve of JSF resources at each level. When cuts are made, it is easy to extend program schedule.

As of the FY 2012 and FY 2013, the JSF Program Office will ensure that the procurement funds for the F-35 and F135 Engines will be outlaid against fixed-price-type contracts. The amount of money spent on the aircraft would be constant so if the price of the jet increases then the number of jets purchased will be decreased in order to keep within budget. The new budget also stipulates that how many jets procured will depend on flight testing progress. This is intended to ensure that production aircraft are combat capable and will not need upgrades once testing is complete (Venlet, 2012).

## **2. The F-35B Probation Episode**

Using Model III with the action channel described above, one can understand the interactions among the players for a major event in the JSF development: the B variant



being placed on and then taken off probation. The B variant was originally designed for the United States Marine Corps and the UK armed forces to replace the aging Harriers (designed in England and produced under license in the U.S.) Both the U.S. and UK have stressed the importance of the STOVL function and because of this, both have been major proponents of the entire F-35 project.

In January 2011 Secretary of Defense Robert Gates placed the F-35B on probation for various issues including a redesign of the propulsion system and necessary fuselage reinforcement needed. There were also issues with the engine overheating. Lockheed Martin insisted that all were engineering problems that could be fixed with more time and money. During the probation period the number F-35B aircraft produced was lowered to 6 per year until 2013. If the problems were not fixed while limiting the total aircraft weight and cost, then this version would be scrapped (Pike, 2011).

The interactions between the different players begin with the DoD. By initially stating that the planes could be canceled, Secretary Gates sent a message to all the players including the members of the DoD, Congress and Lockheed Martin. The Marines as members of the DoD spoke up to say that the plane was essential to their future. General James Amos, Commandant of the Marine Corps, immediately pledged to personally oversee the corrections to the aircraft.

The Marines believe that the capability to take off and land on runways less than 3000 feet provides them with huge tactical advantages. This led to the DoD trying to fix the problem by asking Congress for more money. Congress obliged by appropriating 4.6 Billion more dollars, but mandated updates on program status (Drew, 2011). At this point, the only international partner that was still expressing interest in the B variant was Italy. As of now Italy has not withdrawn from purchasing this aircraft. Furthermore, the UK reconsidered its decision to switch to the F-35C, and is currently back in the F-35B fold.





Lockheed Martin did not want to lose money through the cancelation of this version, so they set to work to address the issues, which were resolved to the point of convincing the new Secretary of Defense Leon Panetta to remove the probationary status in January 2012 after one of the aircraft landed on the Naval Carrier U.S.S Wasp (Shanker, 2012).

## E. Conclusion

The Joint Strike Fighter Program is the largest acquisition project in the history of the DoD and was created to produce a common jet between the Air Force, Navy, and Marine Corps. The program has evolved over the years, and what initially was supposed to be a relatively cheap aircraft, has nearly tripled in price in the last decade due to multiple issues. At the center of these are the problems occurring because of concurrency between testing and production. By using Allison's Model III decision analysis it is possible to look at particular instances in the development of the JSF through the interactions of the players. The most important players in the JSF program are the DoD, Congress, Lockheed Martin, and the International Partners. Looking at the issues with the F-35B in recent years makes it possible to identify the impacts resulting from the efforts of the various players.





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## V. A New Era of Defense Acquisition?

*“Our complexity reach exceeds our engineering grasp.” Well-placed and highly informed DoD official, Ninth Annual Acquisition Research Symposium, May 2012, Monterey, CA.<sup>13</sup>*

US policy regarding the development and purchase of new weapon systems (especially tactical fighters) was stated succinctly and articulately by General Michael Carns, then US Air Force Vice Chief of Staff, in the 1990s: “Our job is to stay one technology iteration ahead of the potential adversary, and ... the F-15 might meet its match. That is not our policy. Our policy is to have air supremacy and to make sure the Army is never attacked” (quoted in Herzog, 1994, p. 25). That US policy was well established prior to Carns’ statement, and has continued to the present day – currently embodied in fifth generation fighters (F-22 and F-35). However, experience with that fifth generation has raised some questions about the continued sustainability of pursuing technical superiority by pushing the envelope of available technology.

In 1987, Norman Augustine offered a series of 35 “laws” about defense acquisition – published in his book naturally titled Augustine’s Laws. Of those, the best known is the 16<sup>th</sup> “Law” which states that the entire U.S. defense budget will buy one tactical fighter aircraft in 2054 (Augustine, 1987, Chap 16, esp. p. 142). A quarter-century later, a number of observers have pointed out that we still appear to be following the pattern of cost that’s consistent with Augustine’s forecast. One such graph from the press (*The Economist*) appears in Figure 2. below.

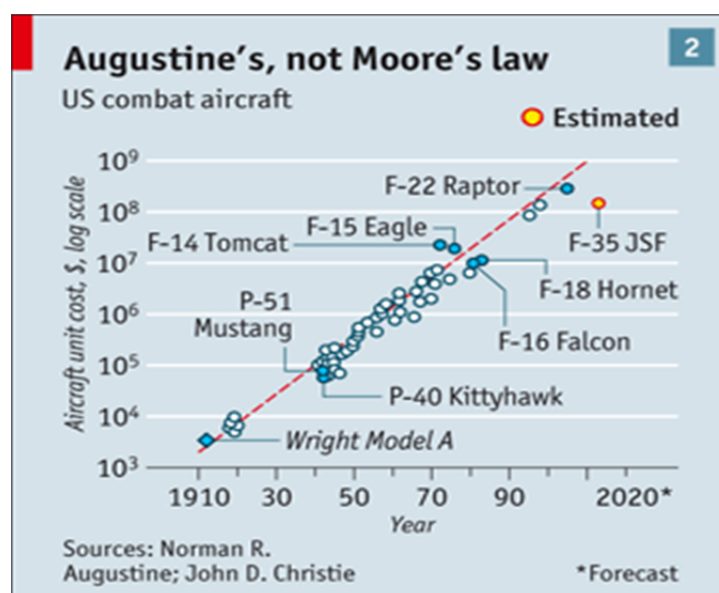
If both defense budget and fighter unit costs are indeed reasonably close to Augustine’s original trend lines (1987, p. 142), this pattern is clearly not sustainable. In

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<sup>13</sup> Comment understood as not for attribution.



that situation, it's impossible to envision any defense establishment being willing (much less able) to purchase manned tactical fighters.<sup>14</sup>



**Figure 2. U.S. Tactical Fighter Cost Trend**  
Source: from *Cost of Weapons* (2010)

That notion is formalized (somewhat) with Herb Stein's "Law" (truism perhaps). One statement is "if it isn't sustainable, it will end" (Winter, 2012). If something indeed ends, it will be replaced by something else. So, if current practices are not sustainable (Augustine)<sup>15</sup> and therefore must end (Stein), it's useful to consider what might replace them. We intend to address that question later in this chapter.

Hence, the purpose in this chapter is to contribute to a necessary discussion. Is the current US design philosophy for weapon systems (especially tactical fighters)

<sup>14</sup> Homage to Augustine's 16<sup>th</sup> Law is currently very fashionable; however, we harbor some reservations. According to our back-of-the-envelope calculations (using a F-35 total unit cost of \$200 M in 2009, 3% real GDP growth to 2054, and defense at 4% of GDP), it appears that tactical fighter costs would have to increase about 23% per year (after inflation) to fulfill the Augustine forecast. That's a rate considerably in excess of the trend line in Figure 2. In current discussions (such as Figure 2), the cost trend line is presented, but not its intersection with the defense budget trend line. However, Augustine [1987, Fig. 20, p. 142] does have a chart that shows an intersection with defense budget around 2050.

<sup>15</sup> Also usefully characterized as "pushing the envelope," to quote the title of a book by Donald Pattillo (1998).

technically and fiscally sustainable? If not, what might replace it? To address that second question, we offer alternative templates, such as “recapitalization” or “replacement” as opposed to “modernization” that embodies major technical advancements. We also consider new initiatives in new engineering design methodology, and concepts of operations.

We first consider (Section V.A) some current symptoms (beyond the Augustine-law trend) concerning doubts about whether current acquisition practices are sustainable. For example, the cost overrun problems of the F-35 Joint Strike Fighter are significant, and have, appropriately, received significant attention. Even more worrying in our opinion is the ever-lengthening time it takes to field new tactical aircraft.

Next, Section V.B takes up an issue we call the Military-Technical Dead End. There are at least three perspectives that are useful in illuminating this concept. One comes from an especially enthusiastic defense critic – Mary Kaldor – whose 1981 book, *The Baroque Arsenal* (esp. pp. 4,19), introduces the very interesting idea of “decadent technologies.” Kaldor is (in our opinion) somewhat vague about what decadent technologies really are; however, we operationalize the idea with increasing marginal cost of performance over time (and newer aircraft types).

Another perspective comes from the Friedmans’ 1999 work, *The Future of War*, which features the also-interesting idea of weapon system senility. This is defined as a weapon type whose defense against opposing countermeasures becomes increasingly important in the design of the system (Freidmans, esp. pp. 138-139, 158). In the end, the senile weapon serves little purpose other than its own protection.

We then essay a synthesis of the Kaldor and Friedman perspectives of the military-technical dead end – based on a simple model of cost, performance, and state of technical art from Sullivan (1981). For a number of reasons, the lines of inquiry (and controversy) we discuss largely petered out after the Cold War ended and the Gulf War of 1991. While there were good reasons for less emphasis on those issues, it’s perhaps time to revisit the critics’ arguments.



One good reason for reconsideration is the difficulties encountered in the current F-35 program (Section V.C) –which looks uncomfortably like a system that embodies a military-technical dead end. There are two troubling possibilities. First is that the pursuit of performance has led to complexity (and expense) that entail fewer units purchased – to the detriment of overall combat effectiveness. A second, and related, matter is time to field new systems. This is troubling in “normal” eras of military affairs; it is especially troubling in an era of multiple RMAs. While the evidence we offer is certainly not conclusive, it does raise interesting and significant questions.

This leads to two troubling questions about the F-35 (and perhaps fifth-generation fighters in general). Have we entered an era of decadent technology in fighter aircraft design? Are manned tactical fighters becoming senile weapon systems (Section V.D)?

Section V.E addresses the question:<sup>16</sup> “if we stop pushing the envelope, what takes its place?” As mentioned, we offer the notions of “recapitalization,” “replacement” and new engineering methods, and new concepts of operations – and offer a few extant examples. The B-52 has been extensively upgraded (recapitalized in a very real sense) over its half-century-plus of operational life – which we explore in a fair amount of detail. The B-52 operational history is a useful exemplar in adapting to new operational environments and countering new threats. We also offer the ideas of “good enough” (e.g., KC-X source selection), new aircraft built within older airframe designs (e.g., CH-53K), and a DARPA initiative to both extend our engineering grasp while potentially restraining our complexity grasp. Finally, we discuss some very interesting and (we think) highly promising concepts of operations within the US military.

#### A. Impacts of the F-35 Delays

*The failure of the so-called fifth-generation fighters ... to arrive on time and on cost is having cascading effects throughout U.S. and allied fighter forces (Sweetman, 2012b).*

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<sup>16</sup> Addresses the question, but does not completely answer it.



The purpose of this particular section is to discuss in more detail the impacts to which Sweetman alludes. While F-35 cost overruns have properly received considerable attention and analysis,<sup>17</sup> we believe the schedule delays are of even more concern.<sup>18</sup> At time of contract award in October of 2001, the F-35A (Air Force version) was expected to become operational (achieve IOC) in June, 2011 (116 months after contract award). In 2011, that IOC had slipped to March 2013. At this time, a 2018-19 estimate appears reasonable (Reuters Staff, 2012; Sweetman, 2012a).

In parallel with the Augustine's Law discussion above, we might also examine development times of tactical aircraft – with the span between original contract award and IOC as one useful metric. The results are shown below in Figure 3 below.

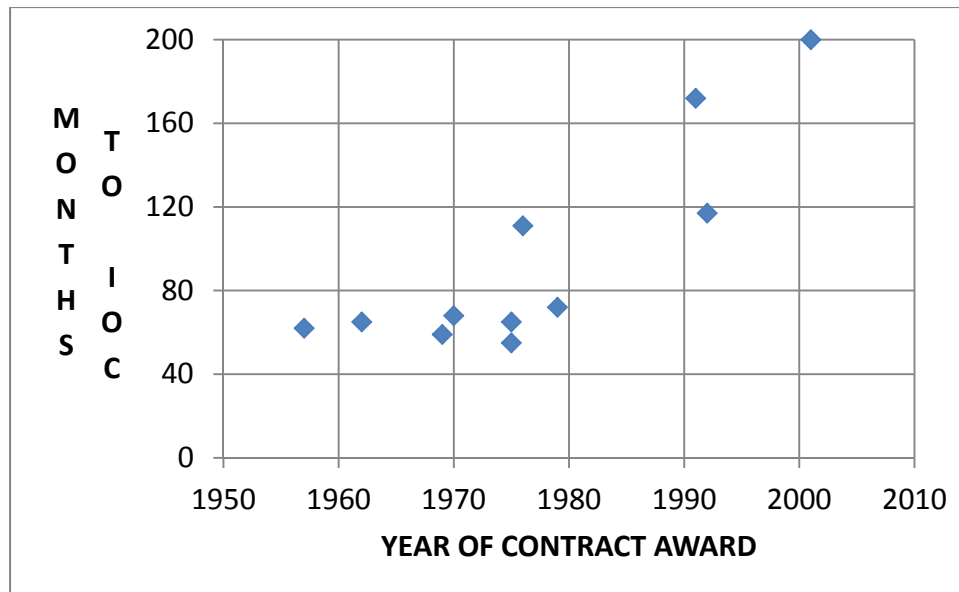
As noted, the current tri-service fighter program arose from an “alphabet soup era of paper airplanes” in the early 1990s, which evolved to “Joint Strike Fighter (JSF)” in 1996 (Aboulafia, 2012, pp. 7-8). That decision fit nicely with the procurement holiday of the 1990s, since it involved substantial cutbacks in procurement of fourth-generation fighters such as the Air Force F-15 and F-16 – with the upcoming fifth generation (F-22 Advanced Tactical Fighter and the JSF) expected to provide timely force modernization in the following decade (Joint Strike Fighter Program, 2012). As one 1990s assessment put it: “With the termination of F-15C/D and the impending halt of F-16 production (except for export markets) ... air force procurement will reach a nadir in the mid-1990s after which aircraft acquisition will be at a standstill until introduction of the F-22 early next decade” (Herzog, 1994, p. 113).

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<sup>17</sup> This includes the RAND and IDA root cause analyses (Arnold, et al., 2010; Blickstein et al., 2011).

<sup>18</sup> And, of course, schedule delays and cost overruns are closely related – in complex ways. Schedule delays generally add to cost. That said, a program delay might lessen concurrency and result in lower overall cost.





**Figure 3. Tactical Fighters: Time to IOC vs. Year of Contract Award**

Sources: Blickstein et al. 2011, Table 4.5, p. 48; Sweetman, 2012a for F-35A.

However, the F-22 did not achieve operational capability (IOC) until late 2005 (Blickstein et al., 2011, p. 48). And the F-35 JSF suffered through a number of well-publicized delays to schedule and cost overruns. Furthermore, with the termination of F-22 procurement at 187 total airframes in 2009 (F-22 Raptor, 2012), the F-35 was the only game in town for US manned tactical fighters. As noted above, the F 35 IOC is now (in all likelihood) likely to occur some time after 2016 (for the Air Force F-35A. the lead model).

With F-22 curtailment and the F-35 delays, there has been a worrisome shortage of tactical fighters in the Departments of Navy and Air Force. The Air Force has stopped acquiring new F-15 and F-16 airframes, awaiting deliveries of fifth generation tactical fighters.<sup>19</sup> The Air Force expects a long-term tactical fighter shortfall (Tirpak, 2010). Also, the Navy has ordered 124 F/A-18E/Fs (Super Hornets), with final delivery

<sup>19</sup> That said, the F-16 production line will likely remain open until 2015 with export sales – perhaps until 2018 depending on Iraqi orders (F-16 International Users, 2012). The F-15 also remains in production – with Saudi Arabia as a major customer for both new aircraft and upgrades (DID Staff, 2012). Both Lockheed-Martin and Boeing could, and almost certainly would, fill new DoD orders for these aircraft.

expected in late 2015.<sup>20</sup> The Navy nonetheless forecasts a fighter shortfall of 177 aircraft in FY2017 (Trimble, 2010) – possibly more with IOC delays for the carrier-capable F-35C.

Somewhat parenthetical to our discussion, but nonetheless interesting, are two implications from Figure 3. above – if the trends displayed continue. First, the hypothetical Augustine Aircraft (assuming an IOC of 2054) would require a quarter century of development. Second, the next-generation aircraft the Air Force discusses (Tirpak, 2010, pp. 38-39; Warwick, 2012c, p. 80) has an IOC of 2030.<sup>21</sup> To achieve that IOC, a contract award in 2010 is indicated. Thus the next-generation fighter appears to be behind schedule already.

## **1. Why F-35 Delays Are a Matter of Concern**

There are at least three reasons why the F-35 delays are strategically significant.

First, there's a gap in capability against opponents with first-rate air defense capabilities. This problem has been highlighted by the much-publicized, upcoming US strategic shift to the Western Pacific (e.g., Marshall, 2012) – which puts a premium on ability to operate against highly capable integrated air defense systems (IADS). As one observer put it, "... existing IADS in Russia and China already may prove impermeable to all U.S. airplanes except the F-22 stealth fighter and B-2 stealth bomber" (Auslin, 2012) Given likely operating areas, ability to project airpower in the most likely operating areas is problematic. As Eaglen and Birkey (2012, p. 4) put it: "With only 185 F-22s and 20 B-2s, the United States has an extremely limited number of stealth aircraft that could participate in a first-wave assault (against a modern air defense system)."

In short, the US DoD has reduced (or stopped) procurement of other tactical fighter systems (including the fifth-generation F-22) –and bet on the F-35 to resolve its

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<sup>20</sup> This package includes some electronic warfare E18-Gs.

<sup>21</sup> General Mike Hostage (Commander, Air Combat Command) describes the 2030 IOC as a "requirement" (Mehta, 2102).





fighter shortfalls. In this context, delays in the F-35 achieving operational status become especially troublesome.

Second, it's reasonable to suspect that the F-35s that are delivered later than originally scheduled will be less effective in the improved threat environments that they will encounter. The interplay of measure and countermeasure in military competitions is a universal fact of life. Moreover, those most closely involved acknowledge that stealth aircraft are no exception. Adversaries will devise countermeasures to stealth, and there will be a corresponding onus on the US and its allies to devise effective counter-countermeasures (Tirpak, 2001). More recently, one Israeli official stated "We think the stealth protection will be good for 5-10 years, but the aircraft will be in service for 30-40 years, so we need EW (electronic warfare) capabilities [for the F-35] that can be rapidly improved" (David and Fulghum, 2012). One point of emphasis here is that the operational value of stealth will decline over time without upgrades.

Therefore it's reasonable to hypothesize that delays in fielding the F-35 will afford opponents with extra time to formulate a program of responses to match or minimize its operational capabilities. While it's difficult to quantify this loss, one approach (Regan and Voigt, 1988, pp. 2-14 – 2-16) is to "depreciate" system effectiveness over the expected life of the airplane. If we suppose that F-35 operational life is 40 years, and that the F-35 will have a delay of 8 years in IOC, then a first-order calculation is that the F-35 will start its service life with 20% (8/40) less capability relative to adversaries than it would have had if delivered as originally scheduled. While there's no particular reason to take 20% loss of relative capability as anything but an upper bound, it's likewise unreasonable to expect that the right answer is no loss at all.

Moreover, schedule delays are potentially very harmful for software-defined fifth-generation fighter aircraft. According to numerous reports, hackers (probably of Chinese origin) achieved significant incursions into F-35 software (Fulghum et al., 2012). Degree of impact – measured in cost, schedule, and lost operational effectiveness – is uncertain based on open reports, and perhaps also uncertain to those with appropriate clearances. However, whatever happened likely resulted in some



information gained that's useful in countering the JSF, and making it less effective in the operational environment it enters when it eventually becomes operational (Gorman, et al., 2009).

Third, the F-35A delays mean spillover costs in other programs. To help bridge the fighter numbers gap, it's been necessary to keep the older, "legacy" aircraft in service for longer than originally planned – and consequently spend more money than originally planned to retard their rate of obsolescence. For example, the US Air Force has been obliged to devote considerable resources to upgrading its "legacy" fourth-generation systems and to extending their operational lives (Better Cost Estimates ..., 2012). These include airframe strengthening and inserting fifth-generation technologies into older fighters<sup>22</sup> – such as helmet-mounted cueing systems, cockpit displays, Infra-Red Search and Track Systems (IRSTS) and new radars (Tirpak, 2011a).

## B. Military-Technical Dead Ends

One aim of this chapter is to raise the question<sup>23</sup> as to whether or not manned tactical fighters have come to an end of the line as cost-effective combat assets. A closely related question is whether the F-35 is the last manned tactical fighter. To help us think about this issue, there are at least two extant perspectives on the matter of military-technical dead ends. First comes from Mary Kaldor (1981), who takes up the subject of "decadent technologies"; the second from the Friedmans (1996) who raise the matter of weapon system "senility."

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<sup>22</sup> A theme to which we'll return later.

<sup>23</sup> We outline the cases for and against the last-stand proposition, but do not intend to reach a conclusion – other than the coming demise of manned tactical fighters not being a frivolous hypothesis.



## 1. Kaldor's Decadent Technologies

Mary Kaldor's *Baroque Arsenal* (1981) was written as a comprehensive indictment of the culture that underpins the technical, industrial and military policies of the major powers – especially the United States.<sup>24</sup>

For reasons related primarily to the internal dynamics of the military-industrial complex, technical “innovations” in weapon systems are almost exclusively pushed along the lines of already developed technology. (Kaldor, 1981, esp. p. 4) Competition among industrial firms seeking to make a favorable impression on their respective Ministries of Defense, is based on pushing near (or beyond) the current state of the art. (p. 18). As part of the sales pitch, expected performance is never understated. At the same time, technical difficulties, time to field, and cost are never overstated. The result is “baroque” technical advance pursued along the lines of “decadent” technologies (p. 19).<sup>25</sup>

The burden of maintaining a coalition sufficient to continue the program over a very large number of annual appropriations drives weapons designs to already-developed technologies with large and established constituencies (pp. 23, 72, 121). Truly innovative processes and performance characteristics wither on the vine. The trend toward ever-smaller numbers of ever-larger acquisition contracts makes such failures increasingly consequential (p. 18).

That is, military equipment gets ever closer to the technical frontier over time – with the inevitable result of increasingly unmanageable complexity (“squeezing too much technology into a single piece of hardware” (pp. 20, 77). One collateral result of

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<sup>24</sup> In our opinion, Kaldor's ideological baggage interferes with the development of some very interesting insights.

<sup>25</sup> Decadent technologies take on at least two meanings for Kaldor. First is pressing the technology frontier along already well-defined lines (“trend innovations”, pp. 4, 22) with corresponding diminishing returns as the design process approaches a technical dead end (pp. 22, 160). Second is emphasis on old technologies that interfere with the development of the economy as a whole (p. 3).



this increasing expense is the need to also stuff more missions into the same platforms (pp. 22, 77) – which is, in turn, a driver of further increased costs (p. 185). Another such result is the complexity of the organization, which lead to huge incentives and coordination problems (pp. 23, 24). Effects of complexity include lower reliability of operational systems, without an appreciable effect on military capabilities (p. 5, 24, 27-28). Moreover, Kaldor maintains that weapon system design processes are generally unrelated to any threat or ongoing military competition. (p. 7).

## **2. The Friedmans and Senile Technologies**

The *Future of War* (1996), by George and Meredith Friedman, was written at the end of the Twentieth Century, and forecasts patterns of warfare for the decades ahead – which was described as an era of long-range, rapid, precision-strike warfare dominated by the United States. (Preface, esp. x-xii). The authors offer a theory of the life cycle of weapons classes – from inception, through significance (perhaps dominance) and then to senility. (Introduction, esp. p. 19). The primary symptom of senility in a weapon is increasing amount of resources devoted to self protection with corresponding loss of offensive power.

The main examples in the book refer to the senility of the “European” classes of weapons. (According to the Friedmans, the basic sources of European military dominance arose from weapons that launched ballistic [unguided] projectiles and explosives.) The European formula peaked in effectiveness in the 19<sup>th</sup> Century, and entered senility in the 20<sup>th</sup> (Part 2, also pp. 27-32).

The two main themes throughout the work are (a) technical innovations translated into military power, and (b) the interplay of measures and countermeasures within ongoing military competitions. This is illustrated through a number of examples. For example, Chapter 5 in *The Future of War* deals with the gun as a land combat system (and subsystem) starting with the late medieval period, and culminating in the rise of armored fighting vehicles (especially tanks) in the twentieth century. The success of tank warfare (especially in World War II) motivated a wide range of



countermeasures – including other tanks, antitank weapons of many types, land mines, ground-attack aircraft, long-range artillery, and guided weapons.

The Friedmans' tank story is essentially a narrative of measure and countermeasure. The counter-countermeasures to the antitank weapons described above largely involved better protection of the tank itself – generally in the form of thicker and more complete armor protection but also active defensive measures (such as reactive armor, Chap 5, esp. 137-140). However, better protection came at a price – larger size and higher rates of fuel consumption. Hence, some vulnerability was transferred to soft-skinned fuel transports rather than eliminated.<sup>26</sup>

As a result of so much attention, and resources, devoted to protecting armored fighting vehicles from a wide variety of battlefield threats, vehicles like tanks became increasingly designed for self defense and less capable of taking the fight to the enemy (Chap 5, esp. 138-139).

However, the Friedmans argue that even the most strenuous efforts at self protection eventually reach a dead end. According to the Friedmans, it comes with the appearance of new information technologies that provide the means to detect armored formations, rapidly orchestrate attacks against them, effectively deliver weapons against them, and then assess the results (for a possible reattack, Chap 5, esp. pp. 142-152).<sup>27</sup>

According to the Friedmans, the tank (and its weapons class) is deep into senility and approaching operational insignificance (Chap 6, esp. pp. 158-159). The *Future of War* also takes on the alleged senility of aircraft carriers (more properly carrier battle groups, Chap 8), and manned aircraft (Chaps 9-12).

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<sup>26</sup> In fact, an emerging orthodoxy in the late 20<sup>th</sup> Century held that the best defense against a large-scale mechanized offensive was to retard the advance of the armored vehicles and emphasize attacks on softer, more vulnerable fuel trucks to starve the tanks of the fuel needed in such large quantities.

<sup>27</sup> This sequence of tasks is frequently called a “kill chain,” a process embedded, inter alia, in Reconnaissance-Strike Complexes – the primary organizational manifestation of the ongoing American-led Revolution in Military Affairs.



The unifying narrative in *The Future of War* goes something like this. Successful weapon classes attract countermeasures. (For every measure, there is almost always a countermeasure.) The countermeasure threat is in turn countered. (For every countermeasure there is almost always a counter-countermeasure.) However, the countermeasure cycles result in an accumulation of defensive features – like armor on tanks and escort vessels for carrier battle groups. This accumulation gradually changes a fearsome offensive weapon system into a system (or system of systems) concerned mainly with its own protection.

The technical-operational dead end for weapons systems in the Friedmans' model arises from causes substantially different from Kaldor's. Kaldor argues that baroque technical advances in pursuit of decadent (dead-end) technologies arises from the politics of military weapons development – pretty much unrelated to threats (Kaldor, 1981, esp. 170-171). According to the Friedmans, however, weapon systems are driven to senility by the pressures of developing threats – that is, from events central to military competitions.

However, both Kaldor and the Friedmans get to roughly the same conclusions. Weapon systems (and classes of systems) have a life cycle that leads to lessened military effectiveness, and eventually military irrelevance. For example, both would label Chobham armor (used on modern tanks) as evidence of a system in decline. Kaldor would emphasize the governmental and industrial processes that drove tanks to baroque innovations (new materials) along the lines of a decadent technology (vehicle armor). The Friedmans would offer this as evidence of armored vehicles' military senility, since the more expensive armor drives tanks (and associated systems) more and more toward mere self protection.

### **3. The Sullivan Synthesis of Military-Technical Dead Ends**

In an unpublished 1981 briefing, Leonard Sullivan (former Assistant Secretary of Defense) offered a very interesting view of military technology and weapon system costs that, among other things, can provide a useful synthesis of the Kaldor and Friedman perspectives.



At any given time, there is a technical frontier – the state of the art. All other things equal, cost of a newly-developed product increases as designed performance nears the technical frontier. Moreover, it rises at an increasing rate, and conceivably goes asymptotic at the technical frontier. This is represented in Figure 4 below. However, with technological advances, the frontier shifts to the right over time. Thus, the cost of increasing performance depends on performance built into any given design and the position of the technical frontier. And cost of weapon systems over time vary according to how close performance requirements approach the technical frontier at any given period, and the rate at which the technical frontier is shifting to the right.

This seems a reasonable macro model of design choices. High-cost weapons are byproducts of relentlessly pushing toward the technological frontier. For Kaldor, industrial and military bureaucracies are incentivized to pursue technical advance, and also have incentives to ignore or minimize the costs and risks of doing that. For the Friedmans, enemy countermeasures drive successive designs closer to the design frontier (relative to previous types) – especially in subsystems for defense.

Suppose that unit cost of a new system (e.g., a tactical fighter) depends on unit performance ( $q$ ) and the location of the technical frontier (whose position is measured by  $F$ , a function of time). That is, unit cost ( $C$ ) depends primarily on the difference between the existing technical frontier ( $F$ ) and system performance:

$$C = G(F-q),$$

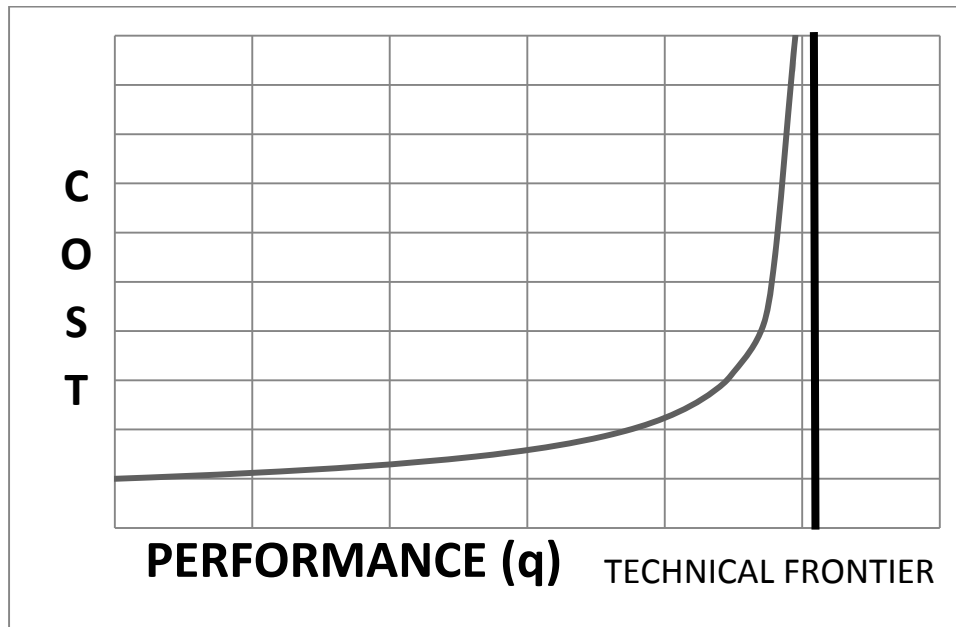
where  $C$  is unit cost,  $G' < 0$ , and  $G'' > 0$ <sup>28</sup> –like the plot in Figure 4. above in which the slope of cost with respect to performance ( $q$ ) is positive and increases as performance increases. That is, as performance ( $q$ ) gets closer to the technical frontier ( $F$ ), then  $(F-q)$  decreases and unit cost increases (since  $G' < 0$ ). Also, as  $q$  increases, the slope of unit cost increases. Normally performance ( $q$ ) increases over time; i.e.,  $q_t$

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<sup>28</sup> Notation defined:  $G' = dG/d(F-q)$  and  $G'' = d^2G/d(F-q)^2$ .



$>0$ .<sup>29</sup> Also the technical frontier shifts outward over time with technical progress; i.e.,  $F_t > 0$ .



**Figure 4. COST VS. PERFORMANCE (Notional)**

Considering total differentials,  $dC = G'dF - G'dq$ , where  $dC$  is the total differential of  $C$  (unit cost), and  $G' = dG/d(F-q)$  [noting that  $\partial(F-q)/\partial F = 1$  and  $\partial(F-q)/\partial q = -1$ ].

Continuing,  $\partial C/\partial q = C_q = -G'$ , which is positive.  $C_q$  is the marginal unit cost of system performance.

Furthermore,  $dC_q = (1) - G''dF - (-1) G''dq = G''dq - G''dF$ , which is the total differential of the marginal cost of performance and

$$dC_q/dt = -G'' dF/dt + G'' dq/dt = C_{qt},$$

which is the change in the marginal unit cost over time. If  $C_{qt}$  is positive, then changing system performance gets increasingly expensive – a situation that Kaldor and the Friedmans argue is endemic to defense acquisition – albeit for different reasons.

<sup>29</sup> In the notation used here,  $M_x$  is the first partial derivative of the function  $M(X)$  with respect to  $X$ .



The interpretation is straightforward. If system performance ( $q$ ) is getting closer to the (moving) technical frontier ( $F$ ), then the marginal cost of performance is indeed increasing. That is, we have strong indications of decadent technology, or weapon system senility (or both) if  $C_{qt} > 0$ .<sup>30</sup>

It's worth noting that  $C_q$  (marginal cost of performance) changes over time due to both technical and social variables. The main technical consideration is the rate at which the technological frontier is shifting to the right in Figure 4 above. The social consideration is the willingness of decision makers in the acquisition process to pursue technical opportunities (to "push the envelope," Pattillo, 1998).

And a system that involves a perpetual and determined pursuit of increased performance in areas in which the technical frontier is moving outward slowly, then military systems become increasingly expensive. If costs increase more rapidly than budgets expand, then fewer and fewer complex and sophisticated items are acquired.<sup>31</sup>

According to Kaldor, the military-industrial complex is determined to increase performance in decadent technologies – those whose technical frontiers are moving relatively slowly. According to the Friedmans, the pressure of countermeasures leads to performance increases that mitigate enemy threats. In that case, weapons systems increase in cost rapidly over successive generations, and evolve toward increasing emphasis on self-protection. This is when weapon systems enter their time of senility.

There is, moreover, something of a synthesis possible for these two views. Dynamics internal to the defense establishment could conceivably result in a determined pursuit of technology embodied in new weapon systems. Relentless pursuit of *mature* technologies (in which Sullivan's technical frontier shifts outward relatively

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<sup>30</sup> Franck (1992, Chap. 3) has a more complete discussion.

<sup>31</sup> This is basically Kaldor's view of the defense acquisition world. However, if the technical frontier moves outward rapidly, then it is possible to have rapid technical advances in fielded products with constant or even declining costs. Personal computers provide one good example of this possibility.



slowly) can, in turn, lead to increasingly large marginal costs of additional performance – the decadent technologies trap.

However, the pressure of well-chosen countermeasures of military rivals can also result in a defense establishment pursuing of technology embodied in new weapon systems – as counter-countermeasures. Moreover, the extent to which the pattern of counter-countermeasures is defensive in nature, and if the defensive enhancements are along the lines of mature technologies, then (a) the weapon system class encounters the decadent technologies trap, and (b) the time of senility has arrived.

Thus, the Kaldor and Friedman hypotheses are definitely not inconsistent. They might well be complementary. Either (or both) can result in the same state of affairs. Moreover, their effects might be mutually reinforcing.

While Kaldor and the Friedmans have differing hypotheses about how weapons systems have become increasingly expensive, they get to generally the same empirical hypotheses. And their predictions have an uncomfortable likeness to current defense acquisition practices. Performance increases become ever harder and more expensive to come by.

#### **4. Why the Debate Lost Momentum after the 1980s**

By way of context, Kaldor and others (such as Chuck Spinney) constituted a group of rather vociferous defense critics who received considerable attention in the 1970s and 1980s. Among their charges were that the new generation of defense equipment was complex to the point of unreliability; complexity meaning, *inter alia*, more opportunities for something to go wrong (Spinney, 1985). Another assertion was that this same complexity made the equipment difficult to use – especially in combat situations. A good example of this genre in the literature of the times is Cushman (1987).

The poster children for the critics included the F-15 tactical fighter and the Stinger anti-aircraft missile – alleged to be complex and unreliable. However, events



proved the opposite. Fourth-generation tactical fighters (F-15, F-16 and F-18) proved remarkably reliable in both exercises and the Gulf War in 1991 (Rhodes, 1988, p. 74; Canaan, 1991, pp. 16-20). Also, the Stinger – despite its 18-step firing sequence (Cushman, 1987) – proved sufficiently simple for successful use in combat against Soviet forces in Afghanistan.

In short, the critics such as Spinney and Kaldor made some good points but grossly overstated their case. With their complexity-cum-unreliability hypotheses falsified in combat operations (the ultimate test), this group lost a significant amount of credibility. Also, the end of the Cold War shifted the national security policy debate in other directions. (Rhoades, 1988; Canaan, 1991).<sup>32</sup>

Moreover, empirical studies of tactical fighter costs such as Hildebrandt and Sze (1986) indicated a more measured pushing of the envelope than Kaldor, Augustine and others alleged (Kaldor, 1981; Augustine, 1986, esp. pp. 130-138). For example, Hildebrandt and Sze's results indicate the last ten percent of unit cost accounted for about 13% of unit cost rather than 50% -- as Augustine's 15<sup>th</sup> "Law" (1987, p. 138) asserted. Moreover, interpretations of the Hildebrandt-Sze model (such as in Franck, 1992, esp. Chap. 3) showed that observed behavior was consistent with rational pursuit of combat capability with constrained resources.

So, while the authors of these dead-end perspectives have their shortcomings,<sup>33</sup> they nonetheless made interesting points. The DoD acquisition community might do well to reconsider now the possibility that they might have been on to something.

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<sup>32</sup> By the way, it's reasonable to suppose that if the Friedmans had published *The Future of War* a decade earlier, they would have attracted even more attention than they received with a 1996 publication date.

<sup>33</sup> In our opinion, both books (*Baroque Arsenal* and *Future of War*) suffer from the authors' rather shallow knowledge of military affairs. (Franck, 1992, pp. 7-8, and Franck, 2001, pp. 481-2 discuss these points in more detail.) There are exceptions to this generalization, however; the lightweight "fighter mafia" was highly knowledgeable about military affairs and also critical of defense acquisition policies.



## C. Why the Dead-End Issue Is Back: The F-35

As noted above, the original purpose of the Joint Strike Fighter (JSF) was to provide replacements for the F-16 (US Air Force), F-18 (Navy) and AV-8 (Marine Corps) – with merging of the Joint Advanced Strike Technology (JAST) and Advanced Short Takeoff and Vertical Landing (AVSTOL) programs in 1994. A concept demonstration phase was initiated in 1995, with a Joint Operational Requirements Documents (JORD) approved in March 2000 (Blickstein et al., 2011, pp. 36-37). The initial core concept was affordability, to be achieved through commonality (90% goal), as well as reduced production and support costs. (Aboulafia, 2012, p. 8).

In 1996, Boeing (F-32) and Lockheed-Martin (F-35) were selected to design and build full-scale “prototype” aircraft. Initial flights occurred in 2000. In October of 2001, the Lockheed-Martin F-35 was awarded the JSF contract – with the program proceeding to the System Design and Development (SDD) phase (Aboulafia, 2012, p. 8; Blickstein, et al., 2011, pp. 35-36).

What happened within the Joint Strike Fighter program has been the subject of a number of historical and analytical studies including Chapter IV above – many of which are excellent.<sup>34</sup> Our purpose in the text that follows is to capture some of the salient features relevant to this inquiry.

### 1. F-35 Design and Development: An Unusually Difficult Task

Notably, an independent DoD cost estimate in 2001 rated the F-35 as high risk – for both technical and schedule reasons (Blickstein et al., 2011, p. 37). That assessment (especially in retrospect) was quite reasonable. The JSF posed very difficult design and development problems.

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<sup>34</sup> The IDA and RAND root cause analyses (Arnold et al., 2010; Blickstein et al., 2011;), for example, were written with access to a number of documents not available to the public. We chose to rely on secondary sources in this report – the trade being in favor of wider circulation of our report over more direct information. The choice was made easier by the high quality of those analyses, especially taken together.



For example, the F-35 in its various incarnations was expected to be stealthy, supersonic, STOVL and carrier capable. Table 1 below summarizes these expectations. Even though not all F-35 models must meet all these requirements, “affordability” means designing in a high degree of commonality – which means that achieving all four required attributes affects the design for all three models.

The effect was to force the SDD teams to satisfy potentially competing design requirements. For example, small engine inlets are highly useful for reducing radar signature; large inlets are highly useful for STOVL operations; and supersonic capability means a specific shape for the inlets. Hence, STOVL and stealth capabilities are inherently competitive, while supersonic capability further restricts the design menu. These restrictions and constraints, with respect to the stealthy, supersonic and STOVL requirements, are summarized in Table 2 below.

Given the multiple, and sometimes conflicting, constraints on the F-35 design space, it’s not surprising that engineering trades have been difficult at best.

**Table 1. Required Capabilities for Selected US Tactical Fighter Aircraft**

Source: adapted from Blickstein et al., Table 4.1., p. 42.

	Stealthy	Supersonic	STOVL	Carrier-Capable
LEGACY AIRCRAFT				
F/A-18		X		X
F-15/16		X		
PREVIOUS STEALTHY AIRCRAFT				
F-117	X			
B-22	X			
F-22	X	X		
JOINT STRIKE FIGHTER				
F-35	X	X	X(B model)	X (C model)



**Table 2. Desired Features for F-35 Design Requirements**

Source: Adapted from Blickstein et al., 2011, Table 4.6, p. 49)

	STEALTH	STOVL	SUPERSONIC
Engine Inlets	Small	Large	Specific Shapes
Fuel Capacity	Internal Only	Small	Large
Airframe Shape	Specific (radar signature)	Specific (Weight Distribution)	Specific (speed regime transitions)
Materials	Increased for stealthy airframe skin	Light Skin for vertical landing	Strong Skin (speed regime transitions)

## **2. The JSF Theory of Success**

The JSF theory of program success centered on quick development followed by quick transition to high-rate production (Blickstein et al., 2011, p.43). Fundamental assertions in the F-35 success theory are briefly summarized below.

JSF is readily available. DoD assumed, in effect that the F-35 technical demonstration was a prototype (essentially a YF-35), even though it was actually an experimental aircraft (X-35) (Blickstein et al., 2011, p. 50). Keeping with the YF-35 view, a fully producible aircraft was deemed to be realizable through a relatively short and painless development process (Blickstein et al., p. 46-7). Accordingly, the F-35 schedule was tighter (and more success-oriented) than, for example, the F/A-18E/F or the F-22 (Blickstein et al., 2011, p. 47). For example, it was assumed that one F-22 engine (F-119) was sufficient for the F-35 – meaning the F-35 engine would be a relatively easy adaptation of an existing product (Blickstein et al., p.53).

This time it's different. Cost and schedule estimates depended on a number of optimistic assumptions. Acquisition reform measures were assumed to compress schedule and reduce costs (Blickstein et al., 2011, p. 47). Testing would be accelerated through use of advanced simulation methods (Blickstein et al., 2011, p. 37). New manufacturing techniques (e.g., unitized wing) would reduce production costs – which



turned out to be an unrealized expectation due to weight growth (Blickstein et al., 2011, p. 54).

This time it's the same. Initial cost estimates relied on fourth-generation fighters, even though the fifth generation was significantly different, and posed greater design and development problems. Likewise, a 6% weight growth margin was planned – in accordance with development of earlier generations of tactical fighters (Blickstein et al., 2011, p. 47). (Weight growth beyond that 6% became a major development issue.)

### **3. The Story Unravels**

Basically the projected path to F-35 success was paved with a series of framing assumptions. Each of them, taken separately, was at least somewhat optimistic. Moreover, getting down that path entailed all of them. When unexpected difficulties (or problems that were assumed away) emerged in the SDD process, there were cost and schedule difficulties directly related to that problem. There were also “spillover” problems because of effects on other parts of the design (Blickstein et al., 2011, p. 55) As design and development progressed, degree of parts and component commonality melted away in order to meet specific model (especially the STOVL version) performance specifications (Blickstein et al., p. 54).<sup>35</sup> In short, the program plan was something of a house of cards.

For example, with greater than expected weight growth came a need for a more powerful engine -- a larger variant of the F-119 (F-135). This, of course, added cost and delayed development – not only for the engine but also necessitated an airframe redesign – with additional adverse effects on both cost and schedule (Blickstein et al., 2011, p. 52).

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<sup>35</sup> In fact, the new F-35 program executive (Lt Gen Bogdan) has characterized the JSF in its current state as basically three different airplanes with the same name – albeit with some commonality (Bogdan, 2012, p. 1).





Unexpected weight growth also undermined production savings. The original plan called for a relatively inexpensive unitized wing construction; with weight growth, “the wing had to be redesigned and produced ‘the old fashioned way.’ (Blickstein et al., 2011, p. 54).” Collateral damage from unmet expectations also affected lower-tier producers – through delays in finalizing parts and components specifications (Blickstein et al., 2011, p. 55).

Fundamentally, a number of interconnected engineering problems delayed development, which delayed production, which was a major cause (but certainly not the only cause) for cost growth. As the RAND root cause analysis put it: “These schedule delays affected the production schedule. Program affordability depended on a quick ramp-up to a high rate of U.S. production (almost 200 aircraft per year) within six years of first flight. As of the December 2009 SAR (Selected Acquisition Report), the ramp-up in U.S. production will not occur until 2016, and reach only 130 U.S. aircraft per year” (Blickstein et al., p.43).<sup>36</sup>

In short, the unraveling has been a complex story of cascading effects. This particular discussion has intended to convey the “texture” of the JSF’s myriad difficulties. There are many sources with excellent and more detailed discussions of the same topic. These include Arnold (et al., 2010), Blickstein (et al., 2011) and Gertler (2012).

#### **4. Why the F-35 Difficulties Are Important to Defense Acquisition Management Policy**

The F-35 program is experiencing significant difficulties, and has been for some time. Whether it will fully solve its problems remains to be seen. However, it’s worth noting that the aircraft was intended to provide a replacement for the fourth-generation family of tactical fighters that would be (a) affordable, and (b) timely. Instead, it has turned out to be surprisingly expensive and far behind the original schedule.

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<sup>36</sup> Based on more recent developments, a production rate of 130 per year by 2016 seems unlikely.





Put another way, the F-35 began as a serious attempt to break out of the Augustine's (16<sup>th</sup>) Law trend for cost, and the trend toward long development programs for schedule. It's done neither, and provides impressive support for those who believe that defense acquisition along these lines will inevitably become unsustainable – due to resources and time consumed for new weapons systems.

The question of whether the F-35 will be the last manned fighter has accordingly become a topic for serious discussion for those concerned with defense policy and acquisition management. Admiral (Ret) Mike Mullen (formerly Navy Chief of Naval Operations) offered that opinion in 2009: "... there are those that see JSF as the last manned fighter ... And I'm one ... that's inclined to believe that." (quoted in McQuain, 2009) More recently, another retired flag officer (Charles Wald, USAF Ret) stated "We may be on verge of building our last manned fighter" (Mitchell, 2012). So, while reasonable people can disagree, this issue nonetheless will not go away.

While improvements in unmanned aircraft capabilities support the Mullen hypothesis, the F-35 simultaneously weakens the case for manned fighters. Among other things, a human presence airborne is supposed to compensate for hardware (or software) failures. Yet the F-35 is pretty much nonoperational with losses of two advanced systems: the pilot's helmet, and the Autonomic Logistics Information System (ALIS; Bogdan, 2012).<sup>37</sup> In short, F-35 experience seems to support the demise of the manned tactical fighter aircraft in the foreseeable future.

F-35 experience, interpreted more broadly, also supports the end-of-manned-fighter hypothesis. One overarching cause of cost overruns was the flawed "framing assumptions" that underpinned the original cost estimates.<sup>38</sup> Perhaps chief among them was that the demonstration aircraft (Boeing's XF-32 and Lockheed-Martin's XF-

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<sup>37</sup> According to General Bogdan (F-35 program executive) "you don't fly this airplane without a helmet, and "if (ALIS doesn't work, this airplane doesn't work" (p. 10).

<sup>38</sup> To the best of our knowledge, the use of term "framing assumptions" in this context originated with a well placed and highly informed DoD official – who was speaking (2012) in a nonattribution environment.



35) could be regarded as prototypes, as opposed to demonstration (experimental) aircraft (Blickstein et al., 2011, pp. 50-51).

In fact, the prototype framing assumptions were arguably just a symptom of deeper analytical failures. As is hopefully made clear above, the *ex ante* case for a successful JSF program was based not only on optimistic assumptions (common to most new projects) but also on a highly interrelated set of optimistic assumptions. Thus, for example, having the F-35 be affordable depended on a rapid transition to high-rate production; a rapid transition to high-rate production depended on Lockheed-Martin's XF-35 being a real prototype aircraft (or something very close to it). And, it's reasonable for an outside observer to conclude that the prototype assumption came about (at least in part) because it was critical to achieving an affordable result.<sup>39</sup>

In short, the F-35 theory of program success was improbable at best – even from an *ex ante* perspective. The original F-35 program, especially in retrospect, looks more like a gamble than a high-confidence plan with multiple chances for success.

Given the whiff of desperation in the F-35's original plan that's apparent in hindsight, it could be that the current policies and methods for acquiring new generations of tactical fighters is in need of some change. Is this the last stand for manned tactical fighters, as Admiral Mullen suggests?<sup>40</sup> Or is it perhaps time to replace high-technology modernization that pushes the technical envelope and shift to something else?

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<sup>39</sup> The full story is more complex than that, and the RAND and IDA root cause studies (Blickstein, 2011; Arnold, 2010) contain more complete discussions.

<sup>40</sup> In fact, there are good reasons to believe that unmanned combat aircraft are now thoroughly entrenched in US tactical air forces (e.g., Michaels, 2012). That is, a significant cultural change toward less emphasis on manned combat aircraft definitely appears to be in progress.



## D. What Are the Performance Advantages of Fifth-Generation Fighters?

As discussed in Section V.B. above, one observable manifestation of decadent technologies is the increasing marginal cost of performance over time. This begs the question of how one measures performance.

### 1. A Digression on Measuring Fighter Performance

While there's lots of discussion about performance of military systems, there's less systematic effort to measure performance. One can get useful information on performance attributes such as maximum speed, service ceiling, and thrust-to-weight ratio, there's less systematic effort to measure system effectiveness as a whole. One noteworthy initiative was a serious attempt to develop performance measures for a variety of combat system types. It was undertaken by the Analytic Sciences Corporation (ANSER) – mostly in the 1980s and described as the TASCFORM method.<sup>41</sup>

Within that project, the TASCFORM-Air model of combat capability was intended to assess tactical fighters, attack helicopters and bombers with conventional (nonnuclear) missions (Regan and Voigt, 1988, 1-1). Tactical aircraft were assessed in the context air-to-air (“air combat”), and “surface attack” – against both land and maritime targets (2-2). The basic intent of TASCFORM was to systematize observable technical features and combine those with judgments of air combat experts to provide a single-number measure of fighter capability in several operational contexts.

The capability measures applied directly to individual aircraft are organized in a hierarchy:

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<sup>41</sup> Regan and Voigt (1988), for example, include a bibliography of TASCFORM (Technique for Comparative Force Modernization) studies completed under contract with DoD (Appendix C). We will be concerned primarily with their Chapter 2 – the TASCFORM-AIR model.



- Weapon Performance (WP, a function of payload, range, maneuverability and speed);
- Weapon System Performance (WSP, WP plus target acquisition, susceptibility to countermeasures, weapon enhancements, navigation and survivability)
- Adjusted Weapon System Performance (AWSP, WSP plus “obsolescence” and productivity<sup>42</sup>) (p. 2-4).

The basic intention was to track these measures by aircraft types and inventories over time.<sup>43</sup> There are also force measures (p. 2-4), but these are not of immediate concern in this discussion.

Digging a bit deeper into TASCFORM, “payload” for tactical fighters is related primarily to the hard points available to carry weapons (such as air-air missiles, p. 2-4). Range is based on maximum range for combat missions (high-low-high altitude profile) with additions for basing mode and weapons range. Maneuverability is derived primarily from maximum excess power at a standard altitude (15,000 ft). It is closely related to thrust-to-weight ratio, and wing loading (p. 2-5).<sup>44</sup> Speed is assessed using maximum Mach Number (p. 2-5).

Weapon System Performance (WSP) applies a “payload utility” multiplier to the payload measure. This reflects target acquisition capabilities, weapons capability over time, and weapon susceptibility to countermeasures (pp. 2-5 – 2-8). In addition, “range” is modified by a navigation capability multiplier (determined by professional judgment, p. 2-11). The maneuverability measure remains the same (p. 2-6). Finally, speed is modified by a survivability factor, determined by “agility,” signatures, countermeasures suite, and flexibility in weapon delivery profiles (p. 2-13).

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<sup>42</sup> “Productivity” is primarily an assessment of sortie-generation capability – a function of system reliability and other things. (Regan and Voigt, 1988, p. 2-14)

<sup>43</sup> A major part of the motivation for the TASCFORM (and other) exercises was to provide assessments of the correlation of forces between NATO and the Warsaw Pact (Regan and Voigt, esp. p. 1-1). With the end of the Cold War came a considerable lessening in interest in the subject.

<sup>44</sup> Maneuverability defined more broadly would seem to also consider characteristics such as maximum g forces, although likely some would disagree.



Adjusted Weapons Systems Performance (AWSP) modifies WSP with multipliers for sustained sortie generation capability and “obsolescence” (p. 2-14 – 2-15). Sortie generation capability comes from ratings based on expert judgment. “Obsolescence” is taken to be primarily a function of (a) calendar time since IOC, (b) nominal useful life by aircraft class (e.g., 25 years for interceptors), and (c) modifications (which lessen the degree of obsolescence, pp. 2-15 – 2-16).

## **2. Assessing F-35 Performance Using TASCFORM Benchmarks**

The discussion that immediately follows compares the technical characteristics of later-model Fourth-Generation fighters (F-16 C/D and F-18 E/F) with the F-35. Specifically, the comparison is based on Tables 3 and 4 provided below. What’s readily apparent is that the F-35 is considerably more expensive than its fourth-generation counterparts. We also consider what performance benefits come with the price tag.

So, how does the F-35 performance look relative to fourth-generation fighters?

A comparison of the aircraft types in the Weapons Performance dimensions (which emphasize payload, range, maneuverability and speed) shows there’s not much difference.

- Hard points: F-35 has only four hard points in stealthy configuration, ten counting external stations. F-16 has 11; F-18E/F, 9. F-35 has a comparable number of hard points, but only with a severe stealth penalty.<sup>45</sup>
- Max Speed: all three aircraft are all comparable. F-35’s maximum mach number is 1.6+, compared to 1.8 (F-18) and 2+ (F-16). The operational utility of the extra speed is debatable, but the F-35 certainly has no advantage in this area.
- Ferry Range: F-16’s ferry range is 2300 NM; F-18, 1600; F-35, 1200 (with internal fuel).

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<sup>45</sup> As one air combat expert put it, “Real stealth,” Jumper said, “means internal carriage of weapons.” (General John Jumper, USAF Ret, former Commander of Air Combat Command, quoted in Tirpak, 2001).



- Combat Range: 700 NM for F-16; 800 for F-18; and 1200 for F-35. However, F-16 and F-18 ranges are for high-low-high profiles, while the F-35 is a high-high-high profile (presumably an advantage conferred by stealth).
- Maneuverability: Thrust-to-weight ratio is comparable for F-16, F-18 and F-35 at 1.10, 0.96 and 1.07, respectively. Max G's are 9 (F-16), 7.6 (F-18), and 9 (F-35) – also in the same general range. Likewise for wing loading, at 88.3 (F-16), 93 (F-18), and 91.4 (F-35).

In Weapon System Performance, some F-35 advantages are clearly discernible. For target acquisition, all three aircraft types are capable of mounting state-of-the-art radars (AESA). F-35 comes equipped with one, and the F-16 and -18 have AESA radar upgrades planned.<sup>46</sup> With its stealth features, the F-35 is superior in survivability, but its target acquisition and weapons delivery capabilities are similarly vulnerable to countermeasures. All three fighters have similar navigation capability.

Finally, with Adjusted Weapon System Performance, the F-35 is obviously newer than the fourth-generation fighters, but its ability to accommodate hardware upgrades later is open to question (Blickstein et al, 2011, esp. pp. 49, 53).<sup>47</sup> Thus it is quite possible that it will become obsolete (relative to threat) sooner than previous generations of fighters, due, *inter alia*, to restricted ability to adapt to changing operational environments.

It's hard to avoid the conclusion that the only inherent advantage of fifth generation fighters is stealth. The other fifth-generation attributes can be inserted into fourth-generation fighters.

Bottom Line: it's clear from Tables 3 and 4 below that fifth-generation fighters are considerably more expensive than the fourth-generation "legacy" models – without commensurate advantages viewed from fourth-generation performance benchmarks.

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<sup>46</sup> Upgrades to fourth-generation fighters would narrow the cost differences, but are unlikely to eliminate them.

<sup>47</sup> F-35 combat effectiveness would possibly degrade more quickly, because of less ability to adjust to enemy countermeasures (and thus retard "competitive obsolescence").



However, that's not the end of the discussion. As Burbage and Davis (2008) put it, "energy management and maneuverability<sup>48</sup> has little relevance in the threat environment for which the F-35 is being designed." That is, they assert that fourth-generation frameworks (e.g., TASCFORM) for assessing performance are outdated.

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<sup>48</sup> Which are a significant part to fourth-generation performance measures, and even more important to Sprey, and other members of the lightweight fighter mafia (Sprey and Wheeler, 2008). The Burbage and Davis view is also available at Lockheed Martin Press Release (2008), cited in references.



**Table 3. Comparison of F-35, F-18, F-16 Characteristics**

TYPE	SIZE					STANDARD PERFORMANCE CHARACTERISTICS								
	L (ft)	W/S (lb/ ft <sup>2</sup> )	WT (10 <sup>3</sup> lbs)			Max speed	Thrust (10 <sup>3</sup> lbs)			Range (10 <sup>2</sup> NM)		Wing Loa- ding	Max G's	Weapons Hard points
			empty	loaded	max		Dry	AB	T/W	Ferry	Combat			
F-35A	51	35		50	70	M1.6+	28	43	1.07	12(1)	12	91.4	9	4(2)
F-18E/F	56	40	23	37	52	M1.8	22	36	0.96	16	8	93	7.6	9
F-16C/D	49	33	19	27	42	M2+	17	29	1.10	23	7	88.3	9	11

**Table 4. Comparison of F-35, F-18, F-16 Characteristics (continued)**

	STEALTH PERFORMANCE CHARACTERISTICS				PROCUREMENT COST (\$10 <sup>6</sup> )
	Frontal RCS (5)	Radar Detection Ranges			
		vs. F-35 (4)	vs. F-18 E/F (4)	vs. F-16 C/D (4)	
F-35 A	1.5 x 10 <sup>-3</sup>	10	55	100	89 (3)
F-18 E/F	0.1	7 (14)	22 (45)	40 (85)	46 (3)
F-16 C/D	1.2	5 (13)	17 (40)	31 (68)	19 (3)

Notes. For entries not in pure numbers, units are feet, 10<sup>3</sup> pounds, pounds/ft<sup>2</sup>, 10<sup>2</sup> nautical miles, square meters (m<sup>2</sup>), and 10<sup>6</sup> \$US.

- 1) With internal fuel.
- 2) Internal. Six hard points external.
- 3) Price quotation date is 2012 for both F-18 E/F and F-16 C/D. F-35A price from estimated procurement costs averaged over FY11-17 is \$152M (Joint Strike Fighter, 2012). A more comparable F-35 price comes from Sweetman (2012a), which is the \$89M included in this table. (The Air Force offers a full-program average cost of \$112M in then-year dollars [Department of Defense, 2012, p. I-1].) These are flyaway costs, as opposed to average procurement unit costs. The DAU Glossary (2011, pp. 1471, 1916) contains definitions which clarify the distinctions between the two.
- 4) Radars assumed are APG-81 (AESA) for F-35; APG-73 and -79 (AESA) for F-18; and APG-68 and -80 (AESA) for F-16. Numbers in parentheses for F-16 and -18 refer to AESA radars.
- 5) Radar cross sections (RCSs) and radar detection ranges are, for excellent reasons, not publicly released. The data in this table were taken from open literature sources (e.g., Boff 180 and Toan (2005), and Bad Wolf (2011). They should be regarded as reasonable estimates, nothing more.



### 3. What's Special about Fifth-Generation Fighters

Continuing the discussion just above, pre-fifth generation measures of fighter performance (e.g., TASCFORM) arguably do not adequately address fifth-generation features. Thus, our next question: what are the performance advantages of fifth-generation fighters?

Fifth-Generation Fighter Enthusiasts can claim that the TASCFORM methodology above was designed to measure performance of Third- and Fourth-Generation tactical aircraft – not Fifth. Given the increased importance of situational awareness (and its denial through stealth), there seems to be considerable truth in this argument.

We start with definition of a fifth-generation fighter. What distinguishes the new generation from earlier fighter types? Table 5 below provides a sampling of viewpoints. (As is evident, there are a number of other fifth-generation definitions extant.)

As is evident in Table 5 below, Goon (2009) has by far the most extensive list. We take Goon's list as describing an ideal fifth-generation fighter. On the other hand, the "Fifth-generation jet fighter" article (2012) provides a list of "common design elements" and can be regarded as something of a lowest common denominator for fifth-generation fighters. The Tirpak (2009) and Gertler (2012) lists seem sensible middle positions to us.

One interesting result, according to Goon's (2009) assessment, is that the F-35 falls well short of being a fifth-generation fighter – inferior, notably, to the Su-35BM (or S), described as an advanced fourth-generation ("4++") fighter. The only area of F-35 advantages noted in Goon's comparison is in stealth and internal weapons carriage. While we suspect, Goon has something of an F-35 ax to grind, he nonetheless makes (in passing) the very sensible point that many fifth-generation features can be incorporated into fourth-generation tactical fighter airframes.



**Table 5. Fifth-Generation Fighter Characteristics**

Sources: adapted from (a) “Fifth-Generation jet fighter, 2012, (b) Tirpak, 2009; (c) Gertler (2012) and (d) Goon (2009).

CAPABILITY	WIKIPEDIA(a)	Tirpak(b)	Gertler (c)	Goon(d)
Supersonic Cruise	X	X	X	X
High Agility		X	X	X
High Excess Power		X		X
Thrust Vectoring			X	X
Integrated Avionics	X	X		X
AESA Radar			X	X
Sidelooking Radar Apertures				X
Integrated Sensors, High Situational Awareness	X	X	X	X
Engine Power, Growth Potential	X			X
High Combat Ceiling				X
Stealth	X	X	X	X
Large Internal Fuel Load				X
Internal Weapons Carriage	X	X		X

Thus, in our judgment, the inherent distinction between fourth and fifth generation fighters is stealth. Many “fifth-generation” features (e.g., advanced sensors; integrated and networked situational awareness; vectored thrust plus high agility; and high-power engines) can also be inserted into fourth-generation airframes – either in existing aircraft or a new design based on a fourth-generation airframe.<sup>49</sup>

The two notable exceptions to this assertion (from Table 5 above) are super cruise and stealth. It would in all likelihood be very difficult and expensive to modify an existing fourth-generation design for significant supersonic operations. But the F-22 has insufficient fuel for long-duration supercruise, and the F-35 has only

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<sup>49</sup> As is being done, for example, with the CH-53K – a new helicopter based mostly on the existing H-53 design. This is discussed in Section V.5.A. below.

supersonic dash capability. So, while supersonic cruise is advantageous, it's arguably not a major advantage for current fifth-generation fighters – particularly in the Western Pacific where longer-range combat missions are likely. On the other hand, it would be a practical impossibility to make fourth-generation designs fifth-generation stealthy, and fifth-generation aircraft without external stores are always stealthy.

Therefore, we regard as unproven the Laird and Timperlake (2012, p. 88) assertion that the F-35 (and F-22) design inherently embodies a whole host of revolutionary capabilities: “the F-35 is more than stealth, more than a weapons system ... At the heart of the F-35 is a new comprehensive combat systems enterprise.” Much of the “comprehensive combat systems enterprise” hardware could fit (perhaps more readily) into a fourth-generation airframe – as noted above.

#### **4. Does the F-35 Embody Decadent Technology? Weapon System Senility?**

As noted above, the presence of large costs for relatively small performance advantages is the hallmark of a decadent technology (according to Kaldor, 1981). We considered a number of characteristics of fighter performance, and noted that the F-35 is significantly more expensive than its fourth-generation predecessors (F-16 and F/A-18). Hence, while there are many differences between Fifth- and Fourth-generation fighters, the *inherent* distinction is stealth capabilities. Since a number of fifth-generation characteristics can be installed in fourth generation airframes, then a significant part of the additional fifth-generation cost has apparently been due to stealth capabilities.<sup>50</sup>

These leaves open two interesting questions, based on the paradigms offered by Kaldor (1981) and the Friedmans (1996). First, with fifth-generation fighters, we

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<sup>50</sup> Just how much of that extra cost is due to stealth and how much to improved situational awareness has not yet been estimated (to the best of our knowledge). A credible assessment is that putting fifth-generation features in fourth-generation airframes would reduce, but not eliminate, the cost differences.



may well have wandered into the realm of decadent technologies. Empirical studies that included fourth-generation aircraft like the F-15 and F-18 revealed no evidence of encountering increasing cost for additional performance (Hildebrandt and Sze, 1986; Franck, 1992). However, this might well have happened with the F-22 and F-35 – fifth-generation designs (Kaldor, 1981; Sullivan, 1981).

Second, fifth-generation fighters might also mark the passing of fighter aircraft into system senility. Stealth is a self-protection feature – which apparently accounts for a remarkably large part of the cost of fifth-generation fighters. Also, stealth is a direct cost driver, due to the cost of embedding stealth into operational aircraft. It also increases costs indirectly – by restricting the range of trades available when translating specifications into engineering designs (Blickstein, et al., 2011, esp. pp. 48-49).

## **5. A Fifth-Generation Reply**

The synergy that results from combining stealth, speed, maneuverability, persistence, information fusion and situational awareness, improved sustainability, lean deployment and the ability to work within and interact with a broad array of networked systems in a single platform represents a quantum leap in capability and survivability over previous fighters (George Standridge, Lockheed Martin, quoted in Space Daily Staff, 2006).

The Fifth-Generation fighter defenders definitely have a different perspective. New aircraft models – such as the F-22 and F-35 – are seen to manifest a disruptive innovation (perhaps a revolution) in air combat. Consistent with the Standridge statement above, the operational capabilities of the fifth generation are due to the combination (synergy perhaps) of the characteristics cited, and in Table 5 above.

Fifth Generation fighters are thus able to obtain dominant battlefield awareness through a suite of advanced sensors – and rapidly synthesize a unified and coherent picture of the operational situation. The suite of sensors is located both aboard the aircraft (radar, infrared and electro-optical frequencies) and also consist of remote units that transmit information (Deptula, 2011). The F-35 can, in



turn, share its operational picture with other friendly units through high-speed, tightly-networked communications.

With this unified situational awareness to identify, track and strike enemy assets – to include both air and surface assets: “...these aircraft allow us to penetrate denied airspace, collect data that cannot be acquired in any other way, translate that data into decision quality information, and then act upon that information by applying either kinetic or non-kinetic effects” (Deptula, 2011).

In particular, Lockheed Martin states the F-35 will be

- four times more effective than current fighters in air-to-air engagements
- eight times for effective striking surface targets;
- three times more effective in surveillance and reconnaissance plus operations against enemy air defenses. (Space Daily Staff, 2006)<sup>51</sup>

At the same time, reduced signatures (stealth) make fifth-generation fighters very difficult to detect – and thus deprive the opponents of comparable situational awareness. In terms of Boyd’s OODA<sup>52</sup> loop (Hammond, 2001, esp. Chap 8), stealthy features delay (or deny) enemy observation of the operational situation. At the same time, unified situational awareness provides rapid orientation to (interpretation of) the operational situation – at the same time facilitating more accurate decisions and more effective operational action. Fundamentally, fifth generation forces are capable of executing OODA loops very quickly, while disrupting opponents’ execution of their OODA loops. It’s a game-changing innovation – a revolution in air combat.

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<sup>51</sup> We understand these comparisons as intended to apply in operations against modern Integrated Air Defense (IAD) systems.

<sup>52</sup> Observe-Orient-Decide-Act.



Moreover, fifth-generation characteristics, especially stealth, increase the proportion of resources devoted to offensive air operations. A better perspective here is a typical strike package (of many sorties) against a modern, well-integrated air defense (IAD) system as opposed to individual aircraft. Strike packages in the past have devoted considerable resources to supporting the aircraft actually putting munitions on mission-objective targets. These have included assets (of various kinds) used to suppress or destroy enemy air defenses at the first level, and additional aerial tankers associated with those support strike sorties. Table 6 below summarizes this argument.

**Table 6.**  
**Table 7. Typical Strike Packages with Fourth- and Fifth-Generation Fighters**  
**against a Contemporary Integrated Air Defense System (in sorties)**  
 Sources: Adapted from Deptula (2011), and Herzog (1994, p. 93)

Aircraft Roles	Fourth Generation	Fifth Generation
Weapons Delivery	8	4
Escort (“sweep”)	12	4
Air Defense Suppression	13	4
Aerial Refueling*	7	3

\* Stated as KC-135 sorties.

From the table, the strike sorties are 20% and 27% of the entire package for Fourth-Generation and Fifth-Generation forces (respectively). While both support packages are substantial, the table presents a persuasive argument that Fifth-Generation fighters do not represent a trend toward weapon system senility.

Therefore, in direct reply to the “decadence” and “senility” hypotheses, one can state the fifth-generation case as follows. Fifth-generation fighters represent the opposite of decadent technologies. In fact, they are a revolution in operational capability – a major jump in performance. The TASCFORM measures discussed above relied on characteristics of fourth-generation (and earlier) fighters, and have been rendered obsolete by the disruptive innovation embodied in fifth-generation fighters.



Truth is that stealthy aircraft defeat fourth-generation combat systems, and also contemporary integrated air defenses (IADs). The opposing forces' OODA loops are disrupted using stealth capabilities. The ability to observe the operational situation is minimized because stealthy aircraft are not detectable (especially by radar) until the fighter is at fairly close range. Short observation times lessen the ability of the enemy to orient to the situation. That is, stealth enables offensive action against opposing forces, and significantly lessens their ability to defend themselves.<sup>53</sup>

Bottom line: while fifth-generation capabilities are not cheap, they're nonetheless worth the cost. The performance improvement is immense (no decadent technology here), which translates to ability to successfully conduct air offensives against even the most advanced air defense systems with smaller support sorties (non-senility).

## **6. A Skeptical Rejoinder**

The OODA loop case built above is interesting and persuasive if taken at face value, and if the F-35 that's fielded fulfills its operational promise. However, OODA loops are part of military conflict at various levels – not just the tactical. There are also loops associated with measures and countermeasures within military competitions. It appears, for example, that the F-35 will be in production for something like thirty years – plenty of time for rivals to formulate appropriate countermeasures. And, as discussed above, F-35 delay in becoming operational has meant greater opportunities for opponents to prepare and field effective responses.

Furthermore, while stealth lessens vulnerability to enemy action, there are clear dangers of transferred vulnerability in the F-35 future. First, as a fifth-generation fighter, the F-35 is indeed a software-defined aircraft (Fifth Generation

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<sup>53</sup> According to Boyd, who is credited with the OODA (observe, orient, decide, act) Loop concept, the side that executes its OODA loop more quickly generally wins (Hammond, 2001, Chap 8).



Jet Fighter, 2012). Perhaps, it's better described as a software-dependent aircraft, as LtGen. Bogdan's recent remarks indicate (Bogdan, 2012, pp.9-11). As such, the F-35 is likely more vulnerable through countermeasures informed by hacking into relevant computer networks.

Second, a stealthy F-35 doesn't have particularly good range – as is evident from Table 3 above. That means aerial refueling is needed when undertaking deep strike missions. This is especially true in theaters involving long distances (such as the Western Pacific). That translates to reliance upon a decidedly unstealthy structure of aerial refueling orbits and fuel offload tracks. Any refueling location that allows an F-35 to reach its target areas certainly permits a long-range, refueled interceptor (such as the Chinese J-20) to reach the refueling orbit. While it's possible that an air battle that's centered upon the tankers would be a problem the US would like to have, it nonetheless means more support sorties for the strike aircraft (and narrowing the differences shown in Table 6. above).

#### E. Elements of a Possibly Emerging New Order

If the current order – as exemplified by fifth-generation tactical fighters – is not sustainable, it's reasonable to wonder what might replace it. Some elements of the (possibly) emerging new order are discussed below.

Good enough? More generally, some commentators have noted that the Air Force shifted from “best” to “good enough”—or from modernization to recapitalization of its aerial tanker fleet; the smaller, less capable – but cheaper -- Boeing KC-46 was chosen over the EADS KC-45. As one observer put it, “[DoD is] not going to pay for bells and whistles.”<sup>54</sup> That's the clear message here, and everyone should be heeding that message" (Censer, 2011).

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<sup>54</sup> In our opinion, “bells and whistles” is an unnecessarily pejorative term. The KC-46 decision is better understood as choosing to simply recapitalize rather than undertake a major capability improvement.





## 1. New Technology in Older Airframe Designs?

It's possible to field new systems by incorporating new technology into older airframe designs. For example, the CH-53K is intended to replace the CH-53E helicopter in US Marine Corps service. The CH-53E achieved IOC in 1981 – with a total of 223 being procured (including 46 mine warfare variants). The CH-53K is now scheduled to become operational in 2018 (37 years later). The K model is intended to be a redesigned replacement built to approximately the same basic “footprint.” Changes include a larger cargo hold and relatively minor external changes. Technical upgrades include more uses of composites – for rotor blades and fuselage structure; new engines; improved avionics; external cargo handling system; and fly-by-wire flight controls. Improved operational capabilities include better high-altitude operations, doubled external payload, and higher airspeed (Sikorsky CH-53K Super Stallion, 2012).

Perhaps the most revealing description of the program is “derivative design of the existing CH-53E using mature technology” (CH-53K Super Stallion Helicopter, 2012). Instead of a new rotary wing lifter, the Marines consciously chose to update the current helicopter with new technology in the old airframe.

The program has been, by most accounts, an unambiguous success (e.g., CH-53K Helicopter Program, 2011; Butler, 2012c). So successful that one commentator has accused the Marine Corps of delaying the CH-53K program, so that it won't so obviously outclass the V-22 Osprey (Hooper, 2009).<sup>55</sup> There are a number of reasons not to take Hooper terribly seriously; but such coverage would have no credibility (and would not likely pass an editor's review) were it not for the CH-53K program's clear success.

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<sup>55</sup> How often is DoD accused of dragging its feet in fielding a new system?



## **2. Keeping the B-52 as Primary Strategic Bomber**

The B-52 design first emerged in the 1940s with deployment mainly in the 1950s. The aircraft enjoyed a remarkably long run as a front-line combat aircraft. Its original mission was high-altitude nuclear bombardment. Accordingly, the major design issues included straight wing vs. swept, and turboprop propulsion vs. turbojet (Boyne, 1981, pp. 43-58; Mandales, 1998, esp. Chapter 5). Initial Operational Capability (IOC) was achieved in 1955, joining the B-47 (IOC 1951) and KC-97 (IOC 1950) – and replacing the B-36 (IOC, 1951; retired, 1959) (Boeing B-47 Stratojet, 2012; KC-97 Stratotanker, 1999; Boeing KC-97 Stratotanker, 2012; B-52, Stratofortress, 2011; B-36 Peacemaker, 1999).

With aerial refueling, the B-52 was capable of overflying the Soviet Union and delivering nuclear weapons – with preferred mode of operation involving flight at altitudes too high for air defenses – interceptors and air defense artillery. Alternatively, the B-52 could fly around heavily defended areas (e.g., Moscow) en route to its targets.

However, the Soviet response to the manned bomber threat was pursued vigorously over an extended period of time. The Soviets allocated large amounts of resources to its air defense forces -- a separate military service. (Soviet Air Defense Forces, 2012, provides a useful historical perspective.) In Soviet fashion, the first area heavily defended against air attack was Moscow – with, for example, the SA-1 Guild Surface-to-Air Missile (SAM) deployed in 1955 (S-25 Berkut [SA-1 Guild]<sup>56</sup>, 2012).

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<sup>56</sup> During the Cold War, the missile system known to the Soviets as the S-25 Berkut was known to the West by the NATO term SA-1 Guild. The two nomenclatures arose because the Soviets kept the S-25 designation secret. This is a constant terminology issue in the references cited throughout this section. Since designations such as the S-25 largely became public knowledge after the Cold War, both terms are now available in the open literature. We will use primarily the NATO designators, but not all sources cited here adhere to the convention. Where appropriate, we supply both NATO and Soviet designators.



As a result of greatly improved air defenses, high-altitude overflight of Soviet airspace became increasingly hazardous with missiles such as the SA-2 Guideline (NATO terminology, IOC 1957), and SA-5 Gammon (IOC 1963); also interceptors such as MiG-21 Fishbed (IOC 1959) and the radar-equipped Yak-25 Flashlight (IOC 1955) (S-75 Dvina, 2012; SA-2 Surface-to-Air Missile, 2011; SA-5 Gammon, 2009; S-200VE Vaga, 2009; Yak-25 Flashlight, 2012; Yakovlev, Yak-25, Mikoyan-Gurevich MiG-21, 2012). The new operational environment was dramatically demonstrated with an SA-2 shooting down a US U-2 reconnaissance aircraft near Sverdlovsk in May of 1960 (S-75 Dvina, 2012).

The US adapted in turn, with new weapons and new tactics in the 1960s. To avoid overflight of heavily defended areas, B-52s were equipped with standoff missiles such as the jet-powered Hound Dog -- AGM-28, IOC 1960 (AGM-28 Hound Dog Missile, 2012; AGM-28 Hound Dog, 2012). To penetrate area air defenses, B-52s received upgraded electronic countermeasures (ECM) equipment, and decoys such as Quail -- ADM-20, IOC 1961 (ADM-20 Quail, 2012).

While a serious effort was made to preserve high-altitude capabilities with the supersonic B-58 (IOC 1960, retired 1970, Convair B-58 Hustler, 2012), the main US response centered on new tactics featuring mutually supporting ECM schemes, and low-altitude B-52 penetration of Soviet airspace (especially the northwestern part). KC-135 aerial tankers (IOC 1957; completely deployed, 1965) provided additional fuel needed for low-altitude flight over extended distances (Boeing KC-135 Stratotanker,<sup>57</sup> 2012).

Soviet counters also included prelaunch threats to the US bomber force. Submarine Launched Ballistic Missiles first appeared in 1961 (SS-N-4, range 300 NM; R-13 SS-N-4 Sark, 2000). This was followed by the SS-N-5 (IOC, 1963; range 700 NM; R-21 missile, 2012), and the SS-N-6 (IOC, 1968, range 1450 NM; R-27 ballistic missile, 2012; R-27 Zyb, 2012). Taken together (especially with the longer-

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<sup>57</sup> Both the KC-97 and KC-135 were named “stratotanker.”



range SS-N-6), these threatened to destroy a substantial part of the US bomber force before it could take off in the event of nuclear war.

The ballistic missile prelaunch threats to the US bomber force also included Intercontinental Ballistic Missiles such as SS-7, IOC, 1962; SS-9, “operational” 1966; SS-11, IOC 1966. (R-16/SS-7 Saddler, 2000; R-36/SS-9 Scarp, 2000; UR-100/SS-11 Sego, 2012). An interesting view of that missile threat appears in Blank (2009).

Accordingly, the US bomber force assumed a higher continuous alert status – with part of the force kept on ground alert through most of the Cold War (Blank, 2009; The Story of the B-52 Stratofortress, 2011) and airborne alert from 1960 to 1968 (Operation Chrome Dome, 2012). In addition, the US nuclear forces had command and control aircraft (Looking Glass) continuously airborne from 1961 to the end of the Cold War (Boeing EC-135, 2012).

However, the Soviets continuously improved their air defenses – with, for example, new SAMs such as SA-4s (IOC 1969) and SA-6s (“accepted for service” in 1967) (2K11 Krug, 2012; 2K12 Kub, 2012) -- also a new generation of fighters such as the Su-15 Flagon (IOC 1965) and MiG-23 Flogger (IOC 1970), and MiG-25 Foxbat (IOC 1970) (Sukhoi Su-15, 2012; Su-15 Flagon, 2000; Mikoyan-Gurevich MiG-23, 2012; Mikoyan-Gurevich MiG-25 Foxbat, 2012).

The US response in the 1970s to all this included the supersonic Short-Range Attack Missile (AGM-69), IOC 1972 (Boeing AGM-69 SRAM, 2012) – which enabled launch outside terminal defenses, and a new high-speed, low-altitude penetrating bomber, FB-111A, IOC 1970 (General Dynamics F-111 Aardvark, 2012). It also included substantial upgrades to the B-52 ECM suite (Blank, 2009; Boyne, 1981, esp. pp. 116-119).

But the Soviets continued to take air defense very seriously and fielded ever-increasing capabilities. A new generation of fighters with enhanced capabilities to engage low-altitude bombers (look-down, shoot-down capability) appeared in the 1980s. These included the Su-27 Flanker, IOC 1984; MiG-29 Fulcrum, 1983; and



MiG-31 Foxhound, 1982 (Sukhoi Su-27, 2012; Mikoyan MiG-29, 2012; Mikoyan MiG-31, 2012).

In addition the Soviets fielded a new family of SAMs, based on the SA-10 Grumble (S300), IOC ca. 1979<sup>58</sup> (S-300, 2012; S300 PMU/SA-N-6/SA-10 Grumble, 2012; S-300 PMU, 2012; SA-10 Grumble SA-N-6 HQ-10/15, 2012). The SA-10 SAMs featured site relocation capabilities, plus high-speed, long range missiles with a very large engagement envelope (that included low and high altitudes). When the new generation of interceptors and SAMs was extensively deployed around 1990, the game would have been up for the B-52 as a low altitude penetrating bomber.

Accordingly, the B-52 started its evolution from penetrating bomber to long-range standoff weapons carrier in the 1980s. Coincident with the 1977 decision to cancel the B-1A bomber, development of the long-range AGM-86B cruise missile (AGM-86 ALCM, 2012), IOC 1982, was pursued. With the start of the B-1B program (1981) IOC 1986, (B-1B Lancer, 2012; Rockwell B-1B Lancer, 2012), the Air Force committed to converting all B-52 nuclear weapons carriers to cruise missiles – to include a stealthy advanced cruise missile (AGM-129, ACM, IOC 1990). The US also developed a truly stealthy penetrating bomber, the B-2, IOC 1997 (Northrop Grumman B-2 Spirit, 2012).

With the end of the Cold War, the B-52H was retained as a long-range weapons carrier – for cruise missiles and standoff conventional weapons (B-52 Stratofortress, 2012). The Air Force has continued to upgrade the capabilities of the remaining B-52H aircraft to function in a contemporary, networked combat environment. For example, Boeing has received major funding for activities to support B-52 system sustainment and modifications (AFP, 2010). Modernization for contemporary command and control includes CONECT, a new communications system (Boeing Company, 2011), and equipping the aircraft with a new air-launched decoy (Hale, 2007).

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<sup>58</sup> Open sources vary on the IOC, plus or minus one year.



Other upgrades in the works, or under serious consideration, include increased conventional weapons carriage with the 1760-standard weapons bus, internal rotary weapons launchers, and a new radar. (Tirpak, 2012, p. 34)

Implications of the B-52 Experience: The B-52 is a very useful model for life-cycle management of combat systems. This aircraft had, in fact, many incarnations: high-altitude nuclear bomber in the 1950s; low-altitude bomber with standoff weapons in the 1960s and 1970s; and standoff weapons carrier, an evolution begun in the 1980s.

Remarkably, the B-52 has outlived a number of companion systems (such as B-47, B-58, FB-111) and putative replacements (such as B-70 and B-1A). There were a number of reasons for this, but one of the central themes in this history was that the B-52 was sufficiently adaptable to incorporate new technology and operational modes that would enable effective counters to the ever-improving Soviet air defenses. It was also able to take on new types of mission, such as delivery of conventional munitions during the Vietnam War.

Thus, while long and rather complicated, the history of the B-52 includes suitability for new technology and tactics as main themes. Thus, for example, a mid-80s B-52 (G or H model) would have a veritable archaeology of technologies aboard – ranging from the mid-1940s to the late 1970s.

Key features of the B-52's long and remarkable history include the following. First, the aircraft was over-designed – partly because it was expected to operate in the vicinity of nuclear blasts (Tirpak, 2012, p. 34). This suggests replicating the experience involves more concern with structural strength and less with weight reduction in the design and development phases of systems acquisition.

Second, extensive planning for keeping the B-52 structurally sound, logistically supportable, operationally useful, and adaptable to threats was assumed by both Boeing and the Air Force (Tirpak, 2012, pp. 30, 34). With that planning,



there's reason to believe the B-52Hs remaining in service will still be flying in 2040 – albeit less in front-line combat roles (Tirkpak, 2012, esp., p. 34).

### 3. New Engineering Design Methods

Another way to solve the engineering-complexity conundrum is to extend engineering grasp through improved methods of engineering design. Recognizing that our complexity reach does indeed exceed our current engineering grasp, DARPA, for example, has announced a series of initiatives with the intention of improving engineering design methodology – with the intention of greatly improving ability to field complex systems more rapidly.

As the DARPA program manager defines the problem: “It’s safe to say that the direction we have been going ... is not a sustainable path. We simply can’t continue to spend more and get less for the money we spend. ...The problem is complexity. Even though the systems we are building are much more complex, the way we engineer those systems has not fundamentally changed for about 50 years.” (quoted in Warwick, 2012a, p. 76). Continuing, he stated “We are building tools to enable a designer to create a ‘correct-by-construction’ system, meaning that when we build it, it works the way the design predicts, first time.” (Warwick, 2012a, p. 76) While acknowledging other model-based design initiatives underway, DARPA asserts that their Adaptive Vehicle Make (AVM) program “takes another step, using component models for virtual testing, and manufacturing models to provide automated feedback on cost and schedule” (Warwick, 2012a, p. 76).

According to Warwick, the DARPA initiatives are inspired by design practices in the software and semiconductor industries – which constantly face the problems of getting the next generation of products out the door very quickly, and “which broke through the complexity barrier decades ago” (Warwick 2012a, p. 76).

The current DARPA initiatives are collectively known as Adaptive Vehicle Make (AVM), and use automated design tools, such as Meta (from Vanderbilt University), designed to raise the level of abstraction in the design process, the way





high-level programming languages have for computers (Warwick, 2012a, p. 76). The suite of design tools also includes iFAB (Instant Foundry Adaptive Through Bits) – intended among other things to indeed provide feedback on “manufacturability” in terms of time and cost (Warwick, 2012a, p. 76).

A near-term proof of concept is an infantry fighting vehicle (FANG) design exercise – scheduled to take place over 18 months. The structure includes three design “challenges” with a prize purse totaling \$4million. The first challenge involves participant teams designing the vehicle’s drive train and “mobility system” in three months. The winning design in this phase will be built by iFAB as an “automotive test rig” (Warwick 2012b, p. 78). The second challenge involves designing the chassis and structure; integrating the occupants and auxiliary systems; and also performing virtual tests of performance relative to system requirements. The winning design will then be built as a test rig. The third challenge requires the participants to design and integrate a complete vehicle. The designs will be evaluated by simulation against vehicle requirements. The winning design will then be built as a “production-ready vehicle” (presumably a full-up prototype) and tested by the Marine Corps along with its Amphibious Combat Vehicle (ACV) (Warwick, 2012b, p. 78).

Some Remarks: While we claim no special expertise on modeling, simulation or engineering design, we think two comments about this development are worthwhile. At first blush, it appears that DARPA’s reach might have exceeded its grasp. A model is useful only to the extent that is “validated” – which inevitably avoids some comparison of model results with observed real-world behavior (Sargent, 2007, esp. pp. 127-128). This then begs the question of how one validates a model of a complex system (with at least the potential for “emergent” properties) that has yet to exist.<sup>59</sup> That is, it appears that DARPA proposes to

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<sup>59</sup> An inherent property of complex systems is the possibility of “emergent” behavior. One standard definition, (Complex Systems, 2012) is a system “composed of interconnected parts that as a whole exhibit one or more properties (behavior among the possible properties) not obvious from the





predict the inherently unpredictable, as captured in the apparent contradiction stated by the program manager, “There is no way to know how a complex system works until you build it. We need new approaches that enable us to predict those interactions” (Warwick, 2012a, p. 76). So, even though DARPA may well advance the state of the art in engineering design, there is no real case (yet) visible that credibly promises avoiding the build-test-redesign-build again treadmill upon which the F-35, for example, has spent such a very long time.

While our observation is interesting, and perhaps revealing, we think (after further reflection) it’s oversimplified and that the DARPA initiative is more sophisticated than first appears. To the extent the FANG infantry fighting vehicle design exercise reveals the process that goes with the tools, there’s much more to the story. First, no design is admissible unless it can be input into iFAB for a manufacturing assessment. That seems to imply no components or subsystems at the cutting edge of technology; being new items, there would likely be no validated model to assess the cost and schedule of making them.

This is not a hidden agenda. As Warwick points out, “restricting designers to parameters that allow automatic manufacturability assessments determines the type of vehicle you can build” (Warwick, 2012a, p. 76). And, as the principal iFAB investigator states, “It’s about living within our means, instead of pushing technology and getting cost growth” (Warwick, 2012a, p. 76). In short, the DARPA methodologies seem to be as much about restricting complexity reach as extending engineering grasp.

Fundamentally, the DARPA initiatives have significant potential for facilitating performance-schedule tradeoffs. AVM and iFAB seem to encourage good, albeit second-best, designs – that can be delivered on schedule and on budget.

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properties of the individual parts.” Or, “the emergent is unlike its components insofar as these are incommensurable, and it cannot be reduced to their sum or their difference (Lewes, 1876, p. 412, quoted in article cited just above in this footnote).



Second, we believe the potential innovations that count for most in the long run probably have more to do with process and incentives than automated design tools. The FANG project has, in our opinion, two important process innovations. The design proceeds in stages. Thus, for example, if the second stage of the design is done after the first stage is finalized, there are fewer degrees of freedom than if both stages were undertaken together. This seems to pass up some useful potentials for synergy between (say) the drive train and chassis in FANG, but it will likely result in fewer surprises, and likely less program concurrency

Also, keeping all teams around for the entire design project permits more collaboration and a larger pool for good ideas (as Warwick's articles point out). However, more importantly, it avoids the counterproductive effects of large contracts awarded in a winner-take-all format. A team that doesn't win the Stage 1 competition is not excluded from a Stage 2 win. This approach has immense potential for increasing competition and preserving design skills throughout the industrial base.

#### **4. New Operations Concepts<sup>60</sup>**

The elements of the possibly emerging new order also include emerging, and evolving, concepts of operations for air combat. Some ideas in development center on (a) really good sensors translated quickly (real time) to highly informative presentations of the current state of the operational environment (providing "battle space situational awareness"); and (b) decentralized battle management led by fifth-generation fighters.

The enabling technologies for rapid and (reasonably) total situational awareness center on remote sensors -- with suites aboard satellites, UAVs and combat aircraft. These are the collectors. The basic data collected is processed in

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<sup>60</sup> "Acquisition" defined narrowly doesn't include ideas about how to operate the equipment (concepts of operations). But they can significantly change the acquisition environment (both performance specifications and total numbers procured).



data fusion centers with computer-based recognition and tracking processes (like ARGUS-IS, Gorgon Stare, 2012a). The central objective is a high degree of situational awareness that is rapidly transmitted, well organized for rapid decisions, and widely shared.

With widespread situational awareness, decentralized battle management is then possible.<sup>61</sup> Fifth-generation fighters -- with their inherently high degree of situational awareness through integration of information from both onboard and networked sensor suites -- become the natural first-level battle managers (as “situational awareness machines,” Laird 2012a). This also confers the advantage of a command-and-control network highly resilient with respect to decapitating attacks (provided, of course, the remote sensors remain connected to the combat aircraft).

Variations of this developing ConOps (concept of operations) include use of mixed forces -- that is fifth-generation-centered strike packages combined with remotely piloted vehicles (RPVs) and fourth-generation manned aircraft. In this scheme, fifth-generation fighters rely on their situational awareness to find, track and target enemy assets (air or surface) -- acting as “scouts and observers” and assigning engagement of targets to “legacy” air combat platforms as the preferred mode of operations (Damon, et al., 2011; Wynn, 2012 Sep).

One summary of this scheme is “We will integrate the F-35 with F-16s, F-15Ks, F-15Es, F-22s, and other airplanes in a way that will enhance and increase everybody’s capability” (Lt Gen Jan-Marc Jouas, Commander US Seventh Air Force in Laird, 2012b).<sup>62</sup> A specific proposal for mating different aircraft types comes from

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<sup>61</sup> Some, (e.g., Wynne quoted in Clark, 2011) argue that centralized airborne battle management is obsolete, since platforms such as JSTARS and AWACS are not survivable at ranges close enough for their sensors to be of use. However, Wynne’s hypothesis does not fully make a case against AWACS and JSTARS. Even Wynne grants the high-signature C4ISR platforms a role in the defensive air battle. So, if these platforms can operate somewhere, and if the networking will be as good as Wynne claims, their crews could indeed manage the offensive air battle -- even from beyond the range of their onboard sensors.

<sup>62</sup> Gen Jouas’ rank and position indicate these discussions have backing within the USAF senior leadership.



Wynne: “‘The Wolfpack’; employing two fifth generation platforms with four fourth generation remotely piloted vehicles”<sup>63</sup> (Wynne, 2012).

We view this ongoing discussion as promising for a number of reasons. First, the services are thinking very seriously about ways to wage war with forces that include combat assets other than fifth-generation aircraft. Second, this is in keeping with historical experience with disruptive military innovations. If fifth-generation fighters are indeed significant and disruptive innovations (“game changers”), then there is reason drawn from historical experience to believe that the best way to exploit that potential is through appropriate combinations with older weapons types.<sup>64</sup>

Finally, while the F-35 looks very good if potential performance is actually realized in operational airframes, in all likelihood it will be operational late relative to both the original schedule and the threat environment over its service life.<sup>65</sup> It’s safe to predict that the number of F-35s in service will lag the original projections by something in excess of a decade. Furthermore, even if the US Air Force receives an average of four new F-35s a month (a moderately optimistic projection), it will take more than thirty more years to achieve the current objective inventory of 1763 aircraft. The US Air Force – and other fifth-generation operators – will unavoidably have to figure out ways to operate in environments where fifth-generation fighters are very thin in the sky.

## F. Comments

The purpose of this chapter was to raise questions rather than provide definitive answers. We’ve seen trends in fighter weapons costs that are quite

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<sup>63</sup> Probably RPV versions of F-16s.

<sup>64</sup> Franck and Hildebrandt (1996) offer examples.

<sup>65</sup> As noted above, it’s unlikely that potential opponents will be idle as the F-35 proceeds (slowly) toward operational status. Countermeasures are inevitable, and the pace of the JSF program is providing a significant amount of time to develop those countermeasures.



possibly not fiscally sustainable. We've also observed trends in times to field new systems that are quite possibly not sustainable within contemporary military competitions.

We've presented the cases for and against fifth generation fighters having inherent performance advantages that are in keeping with their increased cost. We've tried to do this in an even-handed manner.

Finally, we've provided some apparently useful elements of a new approach to setting requirements for new weapon systems – if the current approach (pressing the envelope to ensure technical superiority) is found wanting in the new environment (in its technical, operational and fiscal dimensions).

As noted, the overarching question is in two parts. First is whether or not current design and acquisition practices for combat systems, especially tactical fighters, are sustainable – especially in the upcoming “bust” within the well-established boom-and-bust pattern of defense budgets. The second part is “so what?” If current methods are sustainable, then defense “reform” as usually discussed<sup>66</sup> – and if actually successful this time – could resolve most current issues of schedule and cost. If they're not, then it's time to contemplate more fundamental changes. If complexity reach does indeed exceed engineering grasp (and there are good reason to believe that's true), then there's a clear need to engage in a serious discussion about the defense requirements process.

The debate itself should address a number of questions, including the following.

1. What are reasonable timelines for developing operationally effective new weapon systems in an era of multiple Revolutions in Military

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<sup>66</sup> Generally, defense reform is generally understood as better management of new weapon system acquisition programs – with designs taken as given.



Affairs (RMAs)?<sup>67</sup> Inherently RMAs involve rapid changes in the means of warfare and the determinants of the correlation of forces. They are also periods of adaptation on the part of all the major military powers.<sup>68</sup> In contemporary military affairs, these adaptations have been remarkably rapid – a process enabled by new developments in Information Technology.

2. What are the alternatives to the current practices of technical superiority as an operational imperative, and pushing the envelope for new weapon system designs? We've considered some possible elements of a new era.
  - Recapitalization: simply replacing systems that are wearing out with newer platforms with pretty much the same capabilities – for example, the KC-46 chosen pretty much as a straight-up replacement for aging KC-135s.
  - Designing new systems within old “shapes” – for example the CH-53K – instead of completely new designs.<sup>69</sup>
  - Aggressively managing old systems to keep pace with changing threats and new operational environments. In that context, we've extensively discussed the B-52 above.
  - Institutionalizing barriers between weapon system designs that keep us well short of the existing technological frontier, and which at the same time reform design processes. The DARPA-led initiatives discussed above seem to have real promise in both areas.
  - Updating our thinking about operating older airplanes in new environments. Current discussions in the US military that address combining fifth-generation fighters with other aircraft

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<sup>67</sup> Whether a cluster of military innovations constitutes a full-scale RMA is generally not sorted out until well after the fact. However, there are currently three good candidates for the label: the US-led effort first demonstrated during the Gulf War of 1991; the counter-RMA associated with Al Qaeda and similar movements, and the Chinese-centered innovations currently ongoing.

<sup>68</sup> Franck and Hildebrandt (1996) and Franck (2004) discuss adaptation to RMAs in some detail.

<sup>69</sup> Another example. Would the US Navy not have been better off with newer technology in a reworked A-6 airframe (the A-6F), as opposed to the A-12 project?



types (such as RPVs and fourth-generation manned fighters) are both interesting and promising.<sup>70</sup>

Given the current state of affairs – especially with respect to the ongoing budgetary and schedule difficulties in the F-35 program – and given also the alternate models we’ve discussed – it’s indeed time to have that discussion. The approaches outlined above are neither unprecedented nor cheap. But they do have promise of more timely delivery of new combat capability, at somewhat less cost.

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<sup>70</sup> This would also provide some degree of contestability to the US tactical fighter market – as an added advantage. Presently, the F-35 is the only game in town, and the F-35 suppliers act as if that’s so (as lamented in Bogdan, 2012).



## VI. Concluding Observations

We have taken on some seemingly disparate aspects of the global defense environment in this report. As seen in Chapter II, The C-17 in NATO has been a major success – at least so far. In addition, it has significant potential for emulation for similar programs (involving international employment of aerospace systems).

Chapter III considers the case of the T-X trainer aircraft – intended to eventually replace the Air Force T-38. However, the project is now apparently on hold –awaiting developments in defense budgets and the progress of fifth-generation aircraft development (especially the F-35).

Chapter IV exercises the Governmental Politics Model (Allison's Model III) as an explanatory paradigm for understanding developments in the F-35 Joint Strike Fighter program. In previous reports, we've assessed Model III's ability to explain developments in the various KC-X source selection attempts (Franck, Lewis & Udis, 2010), and found that it worked reasonably well. It appears to be a reasonably good explanatory model for the F-35 program as well.

Chapter V is motivated by fifth-generation fighter development programs – which have run well behind schedule and well over cost. These difficulties have raised some fundamental questions about the continued viability of US emphasis on latest-technology modernization in successive generations of aircraft. We explored those difficulties and their implications. In addition, we consider the serious doubts these programs have raised. Finally, we offer some elements of a possibly-emerging new order in US defense acquisition management.

Although these topics are seemingly disparate, they all center in important ways on the F-35 Joint Strike Fighter (JSF). It's a remarkable story. The JSF was conceived as a timely and affordable replacement for AV-8s, F-16s, and F/A-18s. The United States (and its partners) now appear to be committed to the F-35 no matter how much it costs or how long it takes.





Perhaps we are now wandering in a realm of tactical fighters that resembles one of those visited in Gulliver's Travels, in which marvelous new scientific discoveries were expected to greatly improve the welfare of the nation. Unfortunately, "...none of these projects are yet brought to perfection; and in the meantime, the whole country lies miserably waste, the houses in ruins, and the people without food or clothes" (Swift, 1726). So, while the F-35 has great potential, it's yet to be realized – and may never be fully realized – with potentially dire consequences for the defense of the nation.

Our discussion of the C-17 NATO program (Chapter II) considers alternatives to the difficulties encountered in the management of the international partnership for the F-35 (discussed, for example, in Ito et al., 2011). Our inquiries into the C-17 continue our discussion of the F/A-18 international partnership (Franck, Lewis & Udis, 2011b).

The T-X project (Chapter III) is related to the F-35 and other fifth-generation fighters because one aim of the T-38 replacement is provide a lead-in aircraft for fifth-generation fighters. That makes the T-X much more than a pilot training aircraft, and could greatly complicate its development.<sup>71</sup>

Chapter IV is clearly centered on the F-35. We tried Allison's Governmental Politics (Model III) paradigm's explanatory powers within the history (so far) of the F-35 program. We discovered it works pretty well.

In addition, Chapter V considers the implications of the F-35 experience, and raises the question of whether a new approach to acquiring weapons systems (such as tactical fighters) is warranted. All things considered, it appears that serious

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<sup>71</sup> A potentially interesting irony. The F-22 and F-35 were designed with single-seat versions only. That appears to have resulted in a requirement for a highly sophisticated T-X – which would increase the cost of the new trainer.



rethinking is in order, and we've hopefully provided some perspectives for doing just that.



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<sup>72</sup> The missile system designated 2K11 by the Soviets was known as the SA-4 (NATO designator) to the US and its allies. With all such references, we will endeavor to include both designators.



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# 2003 - 2012 Sponsored Research Topics

## Acquisition Management

- Acquiring Combat Capability via Public-Private Partnerships (PPPs)
- BCA: Contractor vs. Organic Growth
- Defense Industry Consolidation
- EU-US Defense Industrial Relationships
- Knowledge Value Added (KVA) + Real Options (RO) Applied to Shipyard Planning Processes
- Managing the Services Supply Chain
- MOSA Contracting Implications
- Portfolio Optimization via KVA + RO
- Private Military Sector
- Software Requirements for OA
- Spiral Development
- Strategy for Defense Acquisition Research
- The Software, Hardware Asset Reuse Enterprise (SHARE) repository

## Contract Management

- Commodity Sourcing Strategies
- Contracting Government Procurement Functions
- Contractors in 21<sup>st</sup>-century Combat Zone
- Joint Contingency Contracting
- Model for Optimizing Contingency Contracting, Planning and Execution
- Navy Contract Writing Guide
- Past Performance in Source Selection
- Strategic Contingency Contracting
- Transforming DoD Contract Closeout
- USAF Energy Savings Performance Contracts
- USAF IT Commodity Council
- USMC Contingency Contracting



## **Financial Management**

- Acquisitions via Leasing: MPS case
- Budget Scoring
- Budgeting for Capabilities-based Planning
- Capital Budgeting for the DoD
- Energy Saving Contracts/DoD Mobile Assets
- Financing DoD Budget via PPPs
- Lessons from Private Sector Capital Budgeting for DoD Acquisition Budgeting Reform
- PPPs and Government Financing
- ROI of Information Warfare Systems
- Special Termination Liability in MDAPs
- Strategic Sourcing
- Transaction Cost Economics (TCE) to Improve Cost Estimates

## **Human Resources**

- Indefinite Reenlistment
- Individual Augmentation
- Learning Management Systems
- Moral Conduct Waivers and First-term Attrition
- Retention
- The Navy's Selective Reenlistment Bonus (SRB) Management System
- Tuition Assistance

## **Logistics Management**

- Analysis of LAV Depot Maintenance
- Army LOG MOD
- ASDS Product Support Analysis
- Cold-chain Logistics
- Contractors Supporting Military Operations
- Diffusion/Variability on Vendor Performance Evaluation
- Evolutionary Acquisition
- Lean Six Sigma to Reduce Costs and Improve Readiness



- Naval Aviation Maintenance and Process Improvement (2)
- Optimizing CIWS Lifecycle Support (LCS)
- Outsourcing the Pearl Harbor MK-48 Intermediate Maintenance Activity
- Pallet Management System
- PBL (4)
- Privatization-NOSL/NAWCI
- RFID (6)
- Risk Analysis for Performance-based Logistics
- R-TOC AEGIS Microwave Power Tubes
- Sense-and-Respond Logistics Network
- Strategic Sourcing

## **Program Management**

- Building Collaborative Capacity
- Business Process Reengineering (BPR) for LCS Mission Module Acquisition
- Collaborative IT Tools Leveraging Competence
- Contractor vs. Organic Support
- Knowledge, Responsibilities and Decision Rights in MDAPs
- KVA Applied to AEGIS and SSDS
- Managing the Service Supply Chain
- Measuring Uncertainty in Earned Value
- Organizational Modeling and Simulation
- Public-Private Partnership
- Terminating Your Own Program
- Utilizing Collaborative and Three-dimensional Imaging Technology

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